Riparian Shade Characterization Study

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King County

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EXECUTIVE SUMMARY

The Green-Duwamish and Washington-Sammamish basins and their tributary streams and watersheds in King County, are the focus of King County's Freshwater Program. As part of the Freshwater Program, King County Department of Natural Resources and Parks (KCDNRP) is developing a hydrodynamic and water quality model of the Green River mainstem from Tukwila to Flaming Geyser State Park above Auburn and of the Sammamish River using CE-QUAL-W2. KCDNRP is also developing hydrologic and water quality models of the tributary basins and mainstem rivers using Hydrologic Simulation Program-Fortran (HSPF). One goal of the Freshwater Program modeling effort is the dynamic simulation of river and stream temperatures in response to meteorological forcing and the reduction of incoming solar radiation by topography and riparian vegetation. One of the challenges to dynamic river and stream temperature predictions is the characterization of the spatial variability of riparian shade and its effect on incoming solar radiation and hence water temperature.

This report summarizes the results of the field work and analyses conducted as part of the *Green-Duwamish Water Quality Assessment: Riparian Shade Characterization Sampling and Analysis Plan* (King County 2004) and additional field work conducted on the Sammamish River during late summer of 2004. Analysis of recent high resolution **Li**ght **D**etection **A**nd **R**anging (LiDAR) data are also evaluated in this report to assess their potential utility in conducting basin-scale riparian shade assessments. The results described in this report will provide more detailed information on riparian shade than was previously available for refinement of the Green River water quality model and allow incorporation of topographic and riparian shade effects into the Sammamish River model. This report also provides a starting point for incorporation of detailed riparian shade information into basin-scale HSPF watershed models that have been developed as part of King County's Freshwater Program.

Based on the preliminary evaluation of the use of high-resolution LiDAR to remotely characterize vegetation cover (primarily tree height), a more spatially explicit and accurate assessment of tree cover appears to be possible. Using the LiDAR-derived tree heights and a uniform Canopy Density of 90 percent results in an encouraging correlation between model-predicted and observed shade (using hemispherical photographic analysis) when the measurements of shade are made in the center of the river channel.

It is recommended that additional hemispherical photos be collected along the Green River mainstem and in smaller tributary basins in August 2005 to provide more observations over a broader range of shade values for use in developing the best approach to incorporating the available LiDAR data into the shade modeling framework.

Further investigation and analysis is needed to develop a method to estimate spatially explicit canopy density estimates from the available LiDAR data.

1.0. INTRODUCTION

The Green-Duwamish and Washington-Sammamish basins and their tributary streams and watersheds in King County, are the focus of King County's Freshwater Program. As part of the Freshwater Program, King County Department of Natural Resources and Parks (KCDNRP) is developing a hydrodynamic and water quality model of the Green River mainstem from Tukwila to Flaming Geyser State Park above Auburn and of the Sammamish River using CE-QUAL-W2. KCDNRP is also developing hydrologic and water quality models of the tributary basins and mainstem rivers using Hydrologic Simulation Program-Fortran (HSPF). One goal of the Freshwater Program modeling effort is the dynamic simulation of river and stream temperatures in response to meteorological forcing and the reduction of incoming solar radiation by topography and riparian vegetation. One of the challenges to dynamic river and stream temperature predictions is the characterization of the spatial variability of riparian shade and its effect on incoming solar radiation and hence water temperature.

Riparian vegetation is an important link between the stream and terrestrial ecosystem. The condition of riparian vegetation also plays an important role in the control of stream temperature (e.g., Beschta and Taylor 1988, Johnson and Jones 2000). Riparian vegetation can reduce the amount of incoming solar radiation reaching the stream surface depending on factors such as time of day, stream aspect, stream width, and height and density of streamside vegetation. Local topography also influences the timing and amount of incoming solar radiation. Solar radiation is the primary source of heat to the stream and plays a central role in the control of stream temperature (Johnson 2004, Sinokrot and Stefan 1993), although recent studies by the Washington State Department of Ecology (Ecology) and others have indicated that at a local reach level hyporheic heat exchange can also be a significant influence on stream temperature (e.g., Pelletier and Bilhimer 2004).

To support the development of the shade component of the mainstem Green River CE-QUAL-W2 model, a field study of riparian vegetation cover along the mainstem Green River was planned (King County 2004) and then initiated in late August 2004. Prior to the field study, an initial analysis based on interpretation of the available orthophoto coverage was conducted by King County to provide the initial shade inputs for model development (Kraft et al. 2004).

This report summarizes the results of the field work and analyses conducted as part of the *Green-Duwamish Water Quality Assessment: Riparian Shade Characterization Sampling and Analysis Plan* (King County 2004) and additional field work conducted on the Sammamish River during late summer of 2004. Analysis of recent high resolution **Li**ght **D**etection **A**nd **R**anging (LiDAR) data are also evaluated in this report to assess their potential utility in conducting basin-scale riparian shade assessments. The results described in this report will provide more detailed information on riparian shade than was previously available for refinement of the Green River water quality model and allow incorporation of topographic and riparian shade effects into the Sammamish River model. This report also provides a starting point for incorporation of detailed riparian shade information into basin-scale HSPF watershed models that have been developed as part of King County's Freshwater Program.

1.1 Study Area

The study area includes the mainstem Green River and the associated riparian corridor between Flaming Geyser State Park and the Green River confluence with the Black River in Tukwila and the Sammamish River that connects Lake Sammamish to Lake Washington (Figure 1).

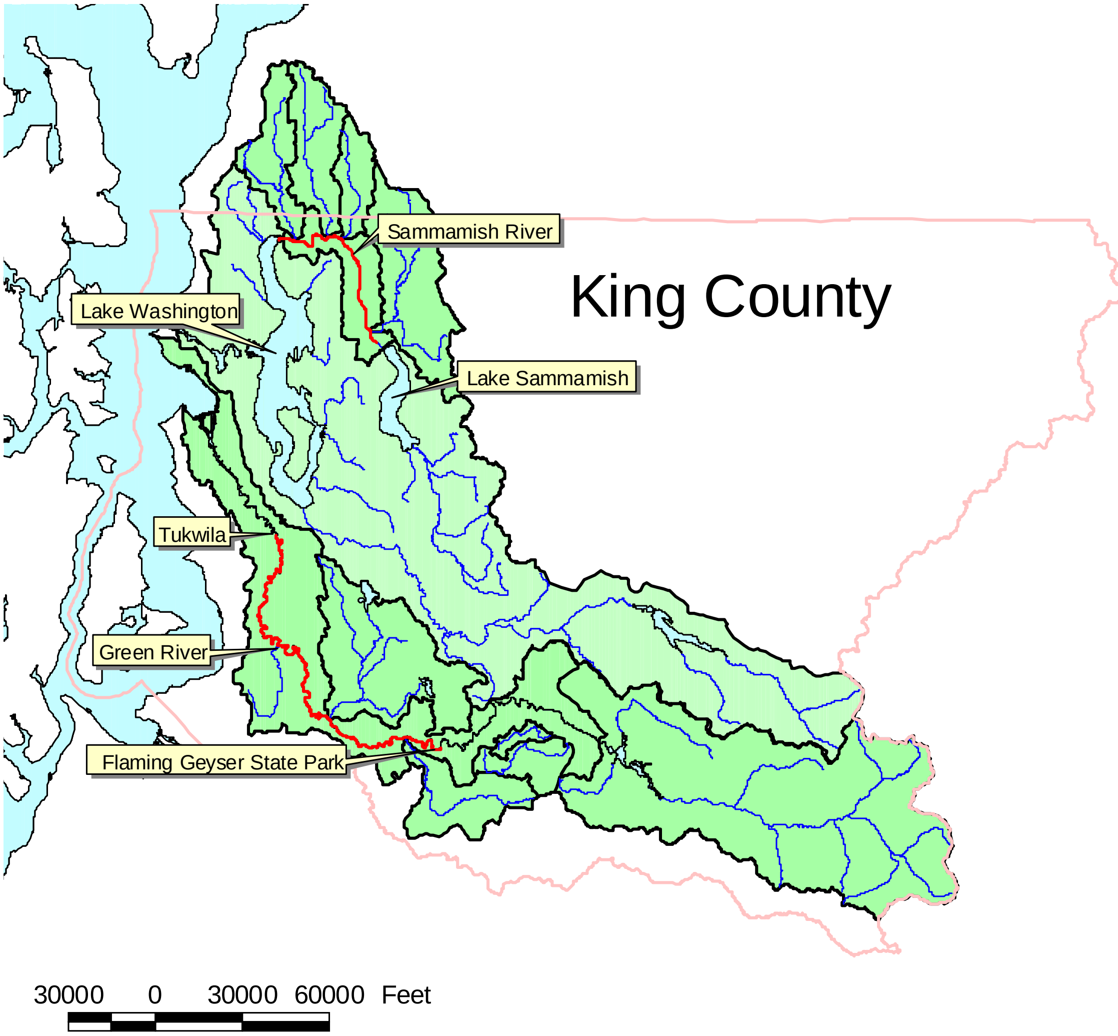


Figure 1. Study area, including the Green and Sammamish River CE-QUAL-W2 model domains shown in red.

1.2 Project Background

The latest version of the CE-QUAL-W2 model (Cole and Wells 2002) contains a dynamic shade routine that incorporates the effects of topography and riparian vegetation on incoming solar radiation. A laterally averaged 2-dimensional water quality model (CE-QUAL-W2) of the Green River mainstrem (Tukwila to Flaming Geyser State Park) was developed for King County by Portland State University (PSU) (Kraft et al. 2004). A CE-QUAL-W2 model of the Sammamish

River was developed for the Seattle-District of the U.S. Army Corps of Engineers to evaluate river temperature management options (Buchak et al. 2001, Jain et al. 2000). The Sammamish River model was further refined by King County and applied to evaluate temperature management options as part of the Sammamish River Corridor Action Plan (DeGasperi 2001 in Tetra Tech 2002). The Sammamish River model was developed in an earlier version of CE-QUAL-W2 that was not capable of dynamic simulation of shade effects. Furthermore, the current version of the Sammamish River model assumes that existing riparian or topographic shade has an insignificant effect on river temperature (Buchak et al. 2001).

An HSPF model of the mainstem Green River from just below Howard Hanson Dam to Tukwila will also be developed. The HSPF code has also been modified to incorporate a dynamic shade routine similar to that used in CE-QUAL-W2 (Bicknell 2003). This will allow incorporation of topographic and riparian vegetation effects on incoming solar radiation within the HSPF model.

In order to set up the dynamic shade models, inputs of stream aspect, topographic shade angles, vegetation height relative to the stream surface, distance of vegetation from the stream, and sun filtering effect of riparian vegetation are needed for each modeled stream segment. All of these inputs, with the exception of the sun filtering effect of riparian vegetation and vegetation height can be derived from high-resolution digital orthophotography and available digital elevation models.

1.3 Goals and Objectives

The overall goal of this study is the collection of data that will facilitate the development and calibration of river and stream water-quality models that include the effect of riparian and topographic shade on water temperatures. The specific goal is the collection of data for the development of the mainstem Green River and Sammamish River CE-QUAL-W2 models.

2.0. METHODS

2.1 Technical Background

Field techniques have been established to measure a number of variables that control the amount of riparian shading and directly estimate the amount of shade cast over the stream surface (e.g., Bartholow 1989, Schuett-Hames et al. 1999, OWEB 1999). The variables that affect the amount of shade include the location of the sun in the sky relative to the local topography and vegetation along the stream, the height of the topography and vegetation, and the density of the vegetation that could block direct sunlight from the stream surface. The vegetation density is often estimated by measuring ***Canopy Density***. Depending on the solar, topographic, and vegetation parameters described above, a certain amount of shade or shadow may (or may not) be cast over the stream surface during the day. The actual reduction in the amount of open sky solar radiation during a specified time period is termed ***Effective Shade***.

Canopy Density and Effective Shade measurements are required for two distinct needs. Canopy Density estimates are required to establish the model input for this parameter and Effective Shade measurements are used to verify that the inputs (Canopy Density, average tree height, etc.) result in reasonably accurate estimates of stream shading. A number of instruments have been developed to measure Canopy Density and Effective Shade. Often one instrument that is suitable for measuring one parameter is not very suitable for measuring the other (OWEB 1999). Instruments selected for use in this study include the spherical densiometer (primarily for measuring Canopy Density) and digital hemispherical photography (primarily for estimating instream Effective Shade).

Canopy Density is used in the calculation of the attenuation of direct solar radiation using a methodology analogous to the Beer-Lambert Law. A vegetation extinction coefficient can be calculated from the following equation:

$$\lambda_{veg} = \frac{\ln(100 - \rho_{veg})}{H_{veg}}$$

where,

λ_{veg}	=	Riparian extinction coefficient (m^{-1})
ρ_{veg}	=	Riparian vegetation density (% Canopy Density)
H_{veg}	=	Riparian vegetation height (m)

Effective Shade is defined as the percent reduction of total solar radiation by topography and or riparian vegetation.

$$\textit{Effective Shade}\ (\%) = \frac{I_o - I_i}{I_o}\ x\ 100$$

where,

I_o	=	Above topography and canopy (i.e., unshaded) radiation
I_i	=	Below canopy (i.e., shaded) incident radiation

Effective shade can be determined as an instantaneous value, but it is often integrated over the course of the day during a critical time of the year when stream temperatures are typically highest.

Field measurements made at the local reach scale are coupled with basin scale aerial photography and other geographic information (e.g., digital elevation models, orthophotos, multi-spectral imaging, etc.) to extrapolate the local effects of streamside vegetation and topography to the basin stream network (e.g., Pelletier 2002, ODEQ 2000, Risely 1997).

It may also be possible to derive vegetation height and canopy density from available high resolution airborne LiDAR data collected as part of the Puget Sound LIDAR Consortium and King County's ESA/SAO Project. The potential for using available LIDAR to develop shade model inputs is assessed in this report.

2.2 Study Approach

The Green River study approach was designed to provide adequate spatial resolution of riparian shade characteristics along the Green River at reasonable cost. Stations located along the mainstem of the Green River between Flaming Geyser State Park and Tukwila were sampled to provide longitudinal resolution of Effective Shade for comparison to model estimates. Surveys of percent canopy density, vegetation height at a subset of sites selected in a stratified design based on the areal coverage of digitized polygons of characteristic vegetation types were proposed to ground-truth the interpretation of the orthophotos and stereophoto pairs. Selection of sites for detailed surveys was based primarily on whether or not they were publicly accessible.

Due to the greater accessibility and navigability of the Sammamish River, data collection focused on the collection of instream hemispherical photographs for comparison to shade model predictions.

Available high resolution LiDAR data were also analyzed as part of this study to evaluate their utility for estimating riparian shade characteristics (primarily tree height and canopy density) for use in the Green and Sammamish River water quality models.

Data analysis was performed using ArcView GIS tools, 3rd party extensions, and extensions developed and adapted by Ecology for developing riparian shade inputs to their stream water quality model. General guidance for the application of these tools available from the Oregon Department of Environmental Quality (ODEQ) was followed (ODEQ 2001). An Excel spreadsheet program developed by Ecology was used to calculate Effective Shade along the Green River mainstem based on the inputs derived from the GIS analysis.

The field study plan and data analysis methods are summarized below.

2.3 Field Study Plan

The Green River study plan contained four components:

- Digital orthophoto analysis, stereophoto analysis and vegetation classification coupled with field assessment to groundtruth/refine vegetation classification scheme.
- Field measurements of vegetation characteristics of representative vegetation types for specification of average percent canopy cover and vegetation height to classified polygons.
- Field measurements of Effective Shade from within or near the stream channel for evaluation of the reasonableness of shade model output.
- Comparison of field-measured vegetation height and canopy density to LiDAR data.

The Sammamish River study focused on the third component above – field measurements of Effective Shade. The study methods are described below in separate sections for each component.

2.3.1 Orthophoto Analysis

ODEQ provides guidance for the digitization/classification of riparian vegetation from digital orthophotos and an ArcView extension called Ttools that can be used to process the available riparian data into model inputs (ODEQ 2001).

The initial analysis that was performed to provide riparian shade data for the Green River CE-QUAL-W2 modeling development effort was based on the 2000 Emerge natural color orthophoto coverage. The more recent analysis was performed using the 2002 USGS natural color photos. Based on this guidance and version 3.3 of Ttools, interpretation of the 2002 orthophotos was conducted by Kathryn Gellenbeck, KCDNRP. Cover classifications relevant to this study were developed for land cover types within a 300-foot buffer from the river centerline. Interested readers are referred to the sampling and analysis plan for additional details (King County 2004).

2.3.2 Field Measurements of Vegetation Characteristics

The Green River field sampling design outlined in the plan (King County 2004) was based on the collection of data representative of the relative areal coverage of each classified tree cover type with a minimum target of 30 vegetation polygons. The sampling plan also outlined a random field sampling approach within each selected polygon. However, conditions encountered in the field (i.e., dense tree cover, dense understory, blackberry thickets) precluded such an objective approach. A decision was made to reduce the scope of the field measurements to three point estimates of canopy density using a spherical densiometer accompanied by a hemispherical photograph at each point. Heights of individual trees identified by common name were measured using a clinometer and laser rangefinder when and where views within or at the fringe of the stand of trees allowed. The field crew also estimated the average height of the tree stand, canopy density and cover type in an attempt to capture average conditions at the survey location.

2.3.3 Field Measurements of Effective Shade

Measurements of Effective Shade were collected in the vicinity of 13 Green River mainstem continuous temperature and routine monitoring locations located between Tukwila and Flaming Geyser State Park (Table 1, Figure 2). Effective Shade measurements in the Sammamish River were made at 57 locations distributed from just below the Sammamish weir transition zone to the mouth of the river near Kenmore (Figure 3). Measurements were made using a digital hemispherical camera system near the center of the channel where possible – all photos taken in the Sammamish River were taken from as near to the channel center as feasible using a boat as a platform. Due to the relatively low flow and channel length in the Sammamish River, navigation by boat was possible over the entire river. Use of a boat was not planned as part of the Green River field work due to safety concerns related to higher water velocities and limited access through some reaches. Therefore, photos from the center of the Green River channel were not always feasible. Where center of channel photos were not feasible, photos were taken on the left and/or right bank where access allowed. Center of channel photos along the Green mainstem were feasible primarily in the upper reach where flow and depth allowed wading access to the center of the channel. Positions where photographs were taken were recorded using a Trimble GeoExplorer II handheld differential global positioning system (DGPS).

Instream hemispherical photos were analyzed in accordance with Ecology protocols (Dustin Bilhimer, pers. comm..) using Hemiview version 2.1 software. Hemiview output for the Global Site Factor (GSF) was used to calculate Percent Effective Shade as follows:

$$\textit{Effective Shade}\ (\%) \quad = \quad (1 - GSF)100$$

Global Site Factor is based on the ratio of below canopy and above canopy total radiation (diffuse and direct) determined for a particular location and day of year by the Hemiview software.

2.3.4 Evaluation of LiDAR Estimates of Tree Height and Canopy Density

Recently, high horizontal resolution (6 ft) LiDAR data have been collected and processed for most of King County (http://www.metrokc.gov/gis/sdc/raster/elevation/index.htm). The LiDAR data have been acquired through a combination of efforts, including data collection by the Puget Sound LiDAR Consortium (PSLC) (http://duff.geology.washington.edu/data/raster/LiDAR/) for Vashon Island and the Seattle-area (2001-2002), and a comparable collection for the remainder of the County and the Water Resources Inventory Area (WRIA) 8 portion of Snohomish County through King County's Endangered Species Act/Sensitive Areas Ordinance (ESA/SAO) Project. These data have been processed into Digital Ground Models (DGMs) and Digital Surface Models (DSMs) (vertical units in feet, North American Vertical Datum [NAVD] 1988). The DGM is an elevation model of the bare ground with buildings and vegetation removed, although bridge and road crossings over streams and rivers remain in all but the Vashon Island coverages. The DSM is an elevation model based on the LiDAR first-return data and is intended to represent the top-of-vegetation or the full-feature surface, including vegetation and buildings.

Table 1. Green River mainstem temperature monitoring locations identified for measurement of Effective Shade

Station ID	Location	Northing	Easting	Source
bic	Bicentennial Park	169706	1290943	King County 1995 study
GRT-22	Van Doren's Landing Park	151427	1283739	GDWQA / King County 1995
G319	Downstream of Mill/Mullen Creeks	141555	1284787	Routine streams
GRT-20	Downstream of Mill Creek Confluence	140411	1290086	GDWQA
nor	North Green River Park	133591	1298422	King County 1995 study
GRT-35	North Green River Park	128160	1300256	GDWQA
GR2	Auburn	117015	1300708	UW / King County 1995
A319	Above confluence with Soos Creek	113108	1307302	Routine streams
GRT-04	Porter Levee	110599	1308604	GDWQA
nee	Neely Bridge	107734	1311323	King County 1995 study
GRT-10	Whitney Bridge	105320	1337495	GDWQA / UW / King County
GRT-36	Flaming Geyser State Park	103780	1341250	GDWQA
GR5	Flaming Geyser State Park – upstream model	102251	1344456	UW

Northing/Easting in State Plane feet, Washington North, North American Datum 1983

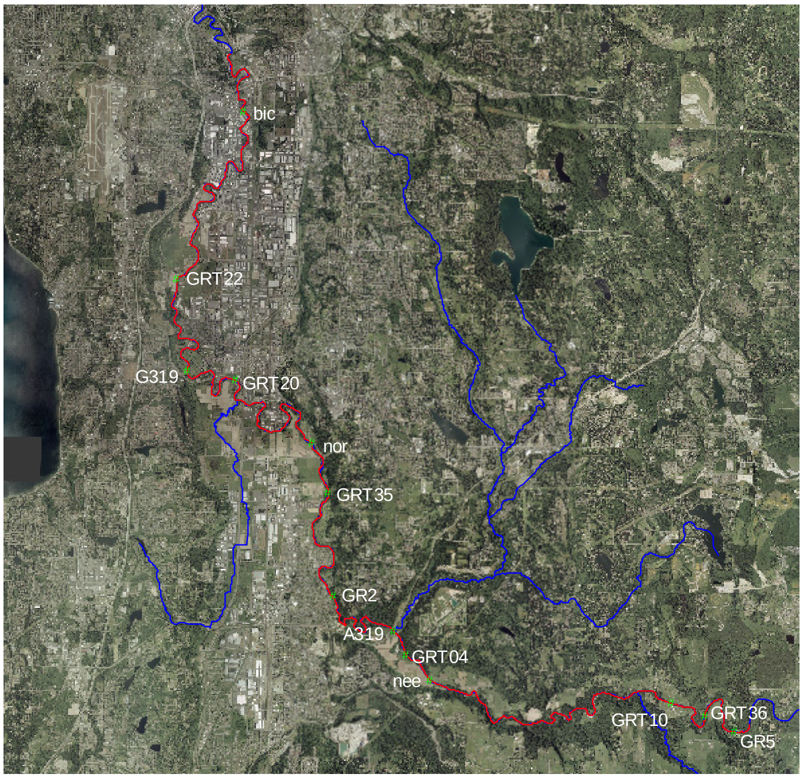


Figure 2. Instream Effective Shade survey locations along the Green River mainstem.

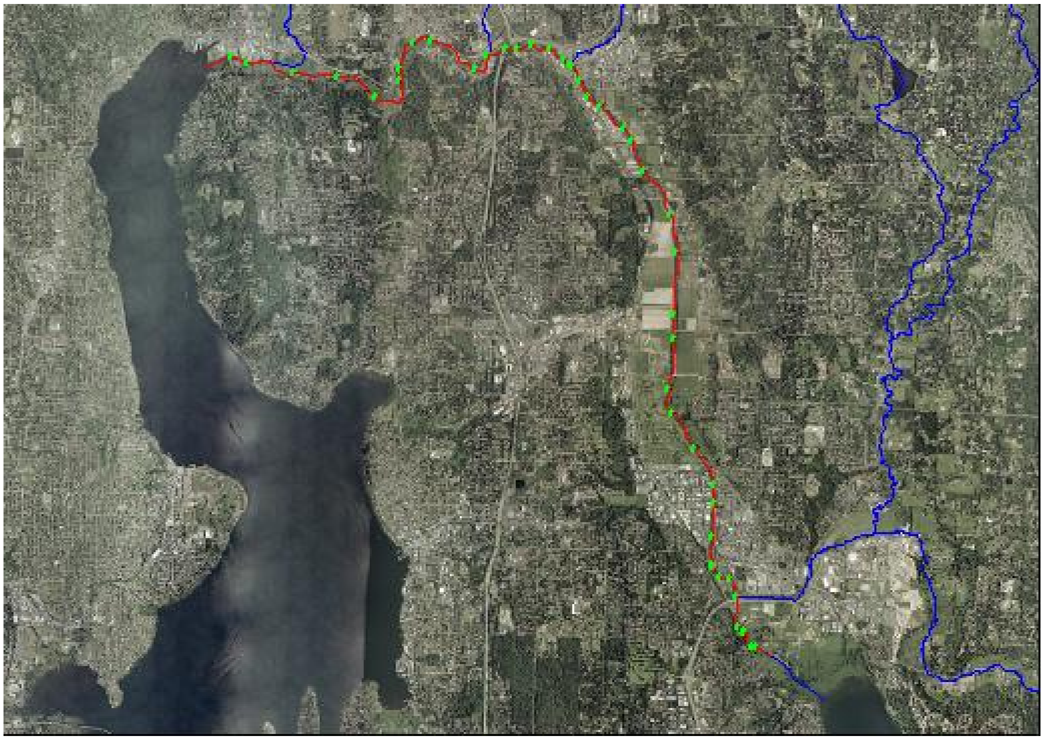


Figure 3. Instream Effective Shade survey locations along the Sammamish River mainstem.

Theoretically, the elevation difference between the DSM and DGM would provide an estimate of vegetation height that could be used directly in calculations of river shading by vegetation. However, the LiDAR flights were conducted during winter to maximize sampling of the bare ground (leaves on deciduous trees would be off during this time), which compromises the utility of LiDAR for estimating deciduous tree heights. To compensate for the possibility that the DSM heights were underestimated due to laser strikes missing the tops of deciduous tree canopies, an approach was taken based on recommendations provided by Mindy Roberts (Ecology) and a forest analysis example provided on the PSLC website (http://rocky2.ess.washington.edu/data/raster/LiDAR/tahuya/tahuya.html).

Two methods were used to calculate surface feature heights from the DSM and DGM grid coverages. Method 1 was as follows:

1. Mosaic the King County Township/Range Digital Surface Model (DSM) and Digital Ground Model (DGM) (e.g., 9 Green River tiles, 6x6 ft horizontal resolution) using the ArcView extension CRWR-Raster (http://www.ce.utexas.edu/prof/olivera/header.htm).

2. Use the ArcView Spatial Analyst Map Calculator to calculate the difference in elevation between the DSM and DGM (nominally the vegetation and building heights (hereafter referred to as the Digital Height Model [DHM]) and convert to a grid coverage at the same resolution (named gr_dsm-dgm and sr_dsm-dgm). This coverage contains negative and zero values due to a few misclassified elevations and exact matches between the DSM and DGM representative of bare ground. Very large positive and negative differences (on the order of thousands of feet), were noted. These differences appear to be related to reflection from water surfaces and glass buildings and did not occur within the stream channel riparian buffer.

3. All values less than 1 in the resulting DHM were set equal to 1 due to requirements of the Ttools grid sampling script.

A second approach to evaluate the utility of LiDAR was also used:

1. Methods were essentially the same as above except that a nearest neighbor analysis was performed on the grid produced in step 3 using the Grid Tools v. 1.1 (Jenness Enterprises) extension (http://www.jennessent.com/arcview/arcview_extensions.htm). Nearest neighbor analysis was performed on a 3x3 grid window. The nearest neighbor maximum was used to better represent the LiDAR-derived vegetation height from deciduous vegetation (The LiDAR was flown after leaf off to optimize sampling for the DGM).

2. The output from the nearest neighbor analysis of the LiDAR data was resampled (using nearest neighbor) to convert the 6x6 ft grid resolution to 18x18 ft.

It may also be possible to estimate Canopy Density from LiDAR, although an analytical approach is not intuitively obvious. Based on the PSLC forest analysis example, the following method was used to estimate Green River canopy cover (not necessarily canopy density) from the LiDAR data.

1. Starting with the DHM created above, assign a grid value of zero to grid cells with a height of less than or equal to 2 meters and a value of 1 for grid cells with a height greater than 2 meters (called Height2m).

2.4 Shade Analysis

The methods currently used by the Washington State Department of Ecology (Ecology) to incorporate vegetation and topographic shade into their temperature Total Maximum Daily Load (TMDL) models were used to process the revised riparian vegetation data into an estimate of effective shade along the Green River mainstem. The basic steps (herein referred to as the "Current Method") were as follows:

1. Digitize river centerline, left bank and right bank using available 2000 orthophoto imagery consistent with the most recent model calibration period (Kraft et al. 2004).

2. Using the ArcView extension, Ttools 3.2 (ttools32.avx), provided by Ecology (Pelletier, pers. comm.), calculate cumulative distance downstream and stream aspect at points spaced 100 ft apart along the digitized river centerline beginning at the upstream end.

3. Measure stream elevation at each stream centerline point above using the ArcView extension Mila Grid Utilities 1.4 (http://www.mila.ucl.ac.be/logistique/sig/sig-tools/milagrid/) and the King County 10 m digital elevation model (DEM) [Note: vertical datum of 10 m DEM is NAVD 1929].

4. Using the Ttools 3.2 extension, calculate stream width and distance from the stream centerline to the digitized left and right bank polylines at each stream centerline point.

5. Using the ArcView Topo4 extension (ttools4.avx), provided by Ecology (Pelletier 2004), and the 10 m DEM, calculate the topographic shade angles within an 8 mile radius of each stream centerline point in the east, west, and south directions.

6. Convert the polygon coverage of vegetation codes (developed in the orthophoto analysis step described in Section 2.2.1 above) to an ArcView grid.

7. Using the Ttools 3.2 extension, sample the gridded vegetation coverage at 15 foot intervals perpendicular to the stream centerline points starting from the left and right banks. A total of 9 points on each side of the river are sampled and assigned a cover code.

8. Using the Ttools 3.2 extension, sample the 10 m DEM at 15 foot intervals perpendicular to the stream centerline starting at the edge of the left and right banks. A total of 9 points on each side of the river are sampled and assigned a corresponding ground elevation in feet for each stream centerline sampling point.

9. The data generated in the steps above are stored in the ArcView stream centerline point coverage (green_veg_base.shp). These data are exported for input to Ecology's Shade program (shade.ver30.xls) downloaded from their web site

(http://www.ecy.wa.gov/programs/eap/models/). Conversion of downstream distance and elevation data in feet to meters is required for input to the shade program.

10. Effective Shade along the river at 100 foot intervals is calculated for a particular day of interest, typically late July or early August when maximum stream temperatures occur in the Puget Sound lowlands.

To evaluate the utility of LiDAR to characterize vegetation and hence riparian shade, the two LiDAR DHM products were tested. Method 1 (6x6 ft grid resolution) was as follows:

1. Steps 1-5 and 8 of the Current Method above were used and the gridded 6x6 ft resolution LiDAR data were sampled using the Ttools 3.2 extension to sample the elevation values at 15 foot intervals perpendicular to the stream centerline points starting from the left and right banks. A total of 9 points on each side of the river were sampled and assigned a height in feet.

2. The data generated in the steps above were stored in the ArcView stream centerline point coverage (green_veg_LiDAR.shp). These data were exported for input to Ecology's Shade program. Conversion of downstream distance, elevation, and height data in feet to meters was required for input to the shade program. A canopy density of 90 percent was assumed for all vegetation (and buildings).

3. Effective Shade along the river at 100 foot intervals was calculated for a particular day of interest, typically late July or early August when maximum stream temperatures occur in the Puget Sound lowlands.

The second method (Method 2, 18x18 ft resolution nearest neighbor maximum grid) was also tested:

1. Steps 1-5 and 8 of the Current Method were used and the gridded 18x18 ft resolution LiDAR data generated by the nearest neighbor maximum analysis were sampled using the Ttools 3.2 extension to sample the elevation values at 15 foot intervals perpendicular to the stream centerline points starting from the left and right banks. A total of 9 points on each side of the river were sampled and assigned a height in feet.

2. The data generated in the step above were stored in the ArcView stream centerline point coverage (green_veg_LiDAR_nn.shp). These data were exported for input to Ecology's Shade program. Conversion of downstream distance, elevation, and height data in feet to meters was required for input to the shade program. A canopy density of 90 percent was assumed for all vegetation (and buildings).

3. Effective Shade along the river at 100 foot intervals was calculated for a particular day of interest, typically late July or early August when maximum stream temperatures occur in the Puget Sound lowlands.

Although vegetation overhang was observed and quantified as part of the Green River field study, it was not included in the shade model comparisons to field data because the field estimates of Effective Shade from the hemispherical photo analysis do not include the effect of vegetation overhanging the channel along the bank. The potential effect of overhanging vegetation on shade model predictions is evaluated as part of the model sensitivity analyses presented in Section 5 below.

3.0. RESULTS

3.1 Orthophoto Analysis

With one exception, the Green River field effort resulted in no changes to the orthophoto-based vegetation classifications. The most upstream polygon on the right river bank in Flaming Geyser State Park was divided into deciduous dominated and conifer dominated stands from the original polygon that was classified as deciduous (see Figure 4). The resulting coverage contained a total of 688 polygons identified as wqa_riparian_081604_111804.shp. The cover classification scheme was also modified to accommodate 3 types of cover by buildings – warehouses, condominium/apartment complexes, and areas of residential housing. The final list of cover classes are provided in Table 2.

Figure 4. Example orthophoto classification (Flaming Geyser State Park).

Table 2. Orthophoto classification cover codes and descriptions

Cover_type	Canopy_cover	Height	Cover_code
Conifer dominated	Dense	Tall	110
Conifer dominated	Moderate	Tall	140
Mix of Conifer and Deciduous	Dense	Tall	210
Mix of Conifer and Deciduous	Moderate	Medium	250
Deciduous dominated	Dense	Tall	310
Deciduous dominated	Dense	Medium	320
Deciduous dominated	Dense	Short	330
Deciduous dominated	Moderate	Tall	340
Deciduous dominated	Moderate	Medium	350
Deciduous dominated	Moderate	Short	360
Deciduous dominated	Sparse	Tall	370
Deciduous dominated	Sparse	Tall	380
Shrub	Dense	Medium	420
Shrub	Dense	Short	430
Shrub	Moderate	Medium	450
Shrub	Moderate	Short	460
Shrub	Sparse	Medium	480
Shrub	Sparse	Short	490
Buildings	NA	NA	500
Buildings-apartments	NA	NA	510
Buildings-residential	NA	NA	520
Open water	NA	NA	600
Grass or cleared	NA	NA	700
Impervious area	NA	NA	800
Depositional bars	NA	NA	1000
NA = Not applicable.			

3.2 Riparian Vegetation Characteristics

Field sampling met the study design goals of collecting data representative of the relative areal coverage of each classified tree cover type with a minimum target of 30 vegetation polygons. Box plots of measured canopy density and tree heights by classification code (Figure 5) indicate that with the exception of the most frequently sampled cover types (i.e., primarily tall and medium tall deciduous cover), small sample sizes and high within site variability preclude any definitive conclusions regarding the assignment of appropriate tree height and canopy density values to specific cover classes. Nonetheless, some generalizations can be made about these results:

- Observed tree heights varied over a range of about 10 to 55 m, but they were most typically between 20 and 40 m regardless of classified cover type.

- Observed canopy density ranged from 50 to 100 percent but was most typically between 80 and 100 percent.

Experience in the field also suggested that point sampling of tree heights and canopy density would not be an efficient means of assessing averages for various classified vegetation types due to the patchiness and variability of tree cover along the river and low number of accessible field locations. A more effective means to develop this information may have been to perform field estimates of average tree height and canopy density for as many polygons as possible based on field and shade modeling experience. Field estimates were made by the field sampling crew, but the limited number of observations and high within site variability for all but the most common cover types resulted in the same limitations as the point sampling data (see Figure 6). Alternatively, individual polygons could have been reclassified based on field observations. Because of the large study area and low number of accessible sites, the original vegetation polygons were maintained. Attributes were assigned the median of field observations.

3.3 Instream Effective Shade

Instream Effective Shade was calculated for August 3, 1998 (a cloudless day based on observations at Sea-Tac International Airport just west of the Green River Basin) from the instream hemispherical photos taken at the Green and Sammamish River monitoring sites identified above using the Hemiview software. An example photo and classified image is provided in Figure 7.

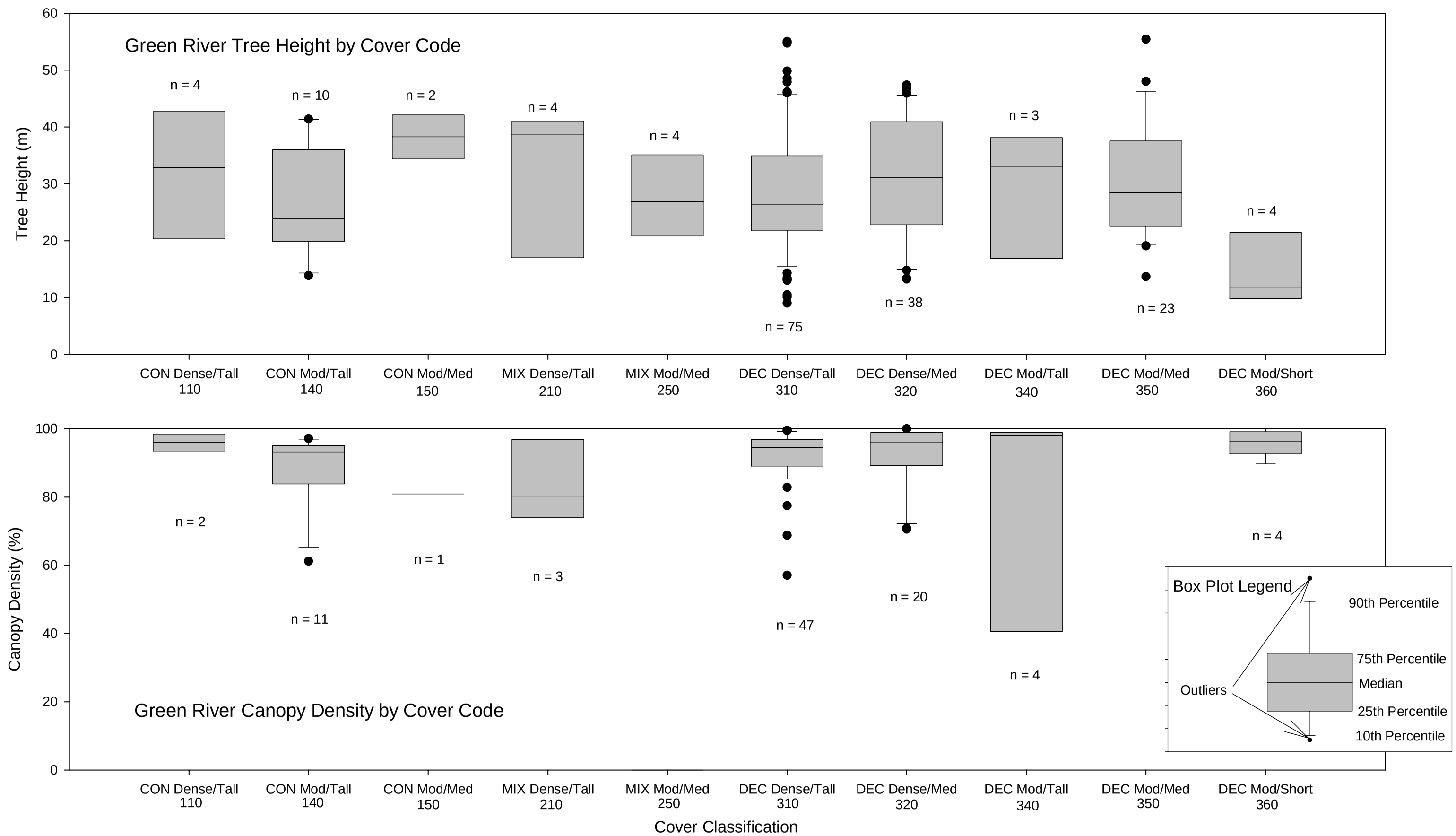


Figure 5. **Distribution of Field-Measured Tree Height and Canopy Density by Cover Classification.**

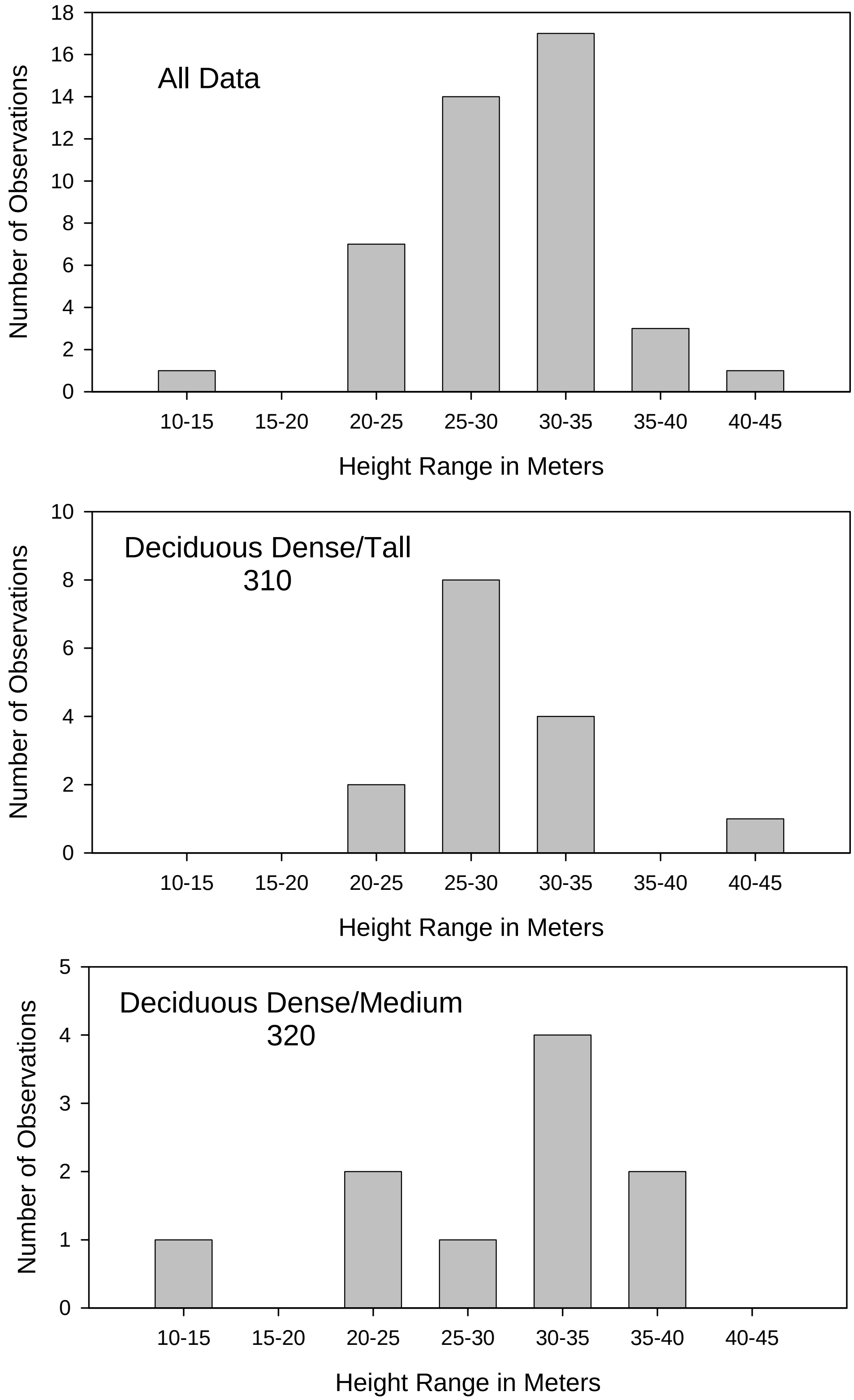


Figure 6. Distribution of Field-Estimated Tree Height for all sampled polygons and for selected Cover Classes.

Figure 7. Example hemispherical photo (left) and classification of processed photo (right). Photo #169, taken at river center near Neely Bridge on September 30, 2004.

3.4 LiDAR Analysis

The raw DHM developed from the mosaiced DGM and DSM grids contained a number of very large negative and positive heights (~ -1,500 to ~ 5,000 ft). Inspection of the grids indicated that these obvious errors were due to errors in the DSM. The cause(s) of these errors is unknown at this time, but inspection of some of the largest errors suggests they are due to reflections from water bodies, large glass covered buildings, and artifacts at mosaiced grid edges. In order to perform the shade analysis, DHM values less than or equal to 1 ft were set to a value of one. DHM values within the 300 ft polygon buffer were then screened to ensure that no unusually large (i.e., greater than about 65 m [213 ft]) values were present. An example view of the 6x6 ft resolution DHM is provided in Figure 8. An example view of the 18x18 ft resolution grid is provided in Figure 9. An example view of the 6x6 ft resolution Canopy Cover (Height >2 m = 1, <=2 m = 0) is shown in Figure 10.

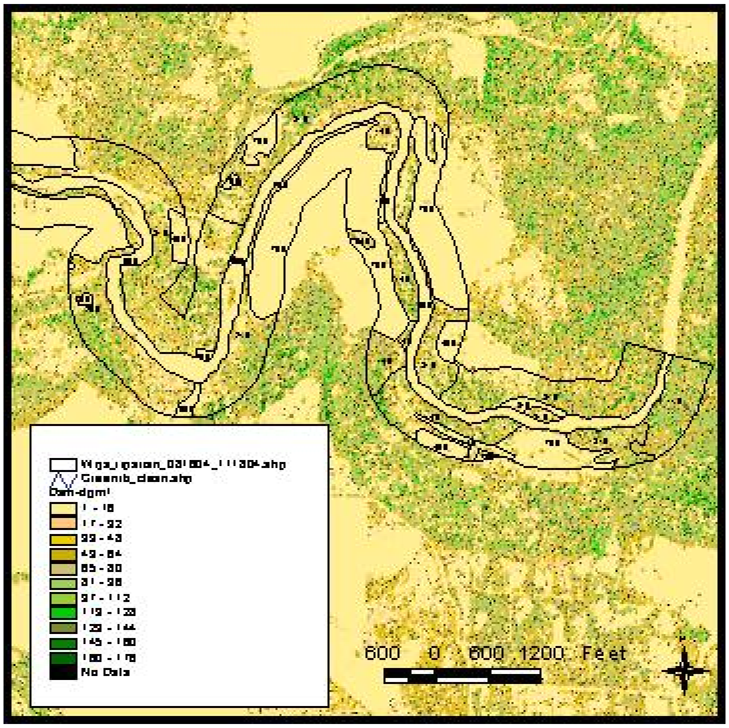


Figure 8. Example LiDAR 6x6 ft resolution Digital Height Model (DHM). Height in feet with nominal bin intervals of 5 m.

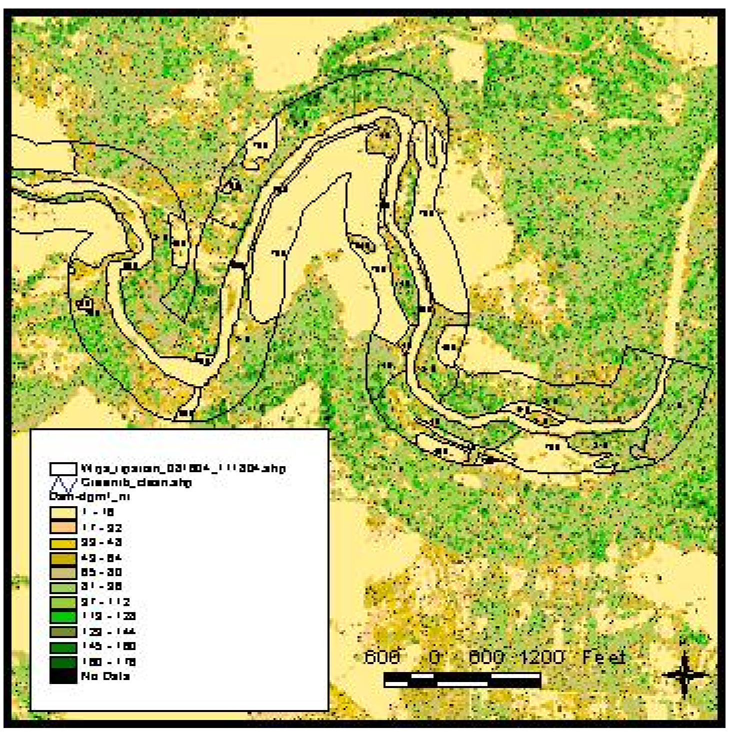


Figure 9. Example LiDAR 18x18 ft resolution Digital Height Model (DHM). Height in feet with nominal bin intervals of 5 m.

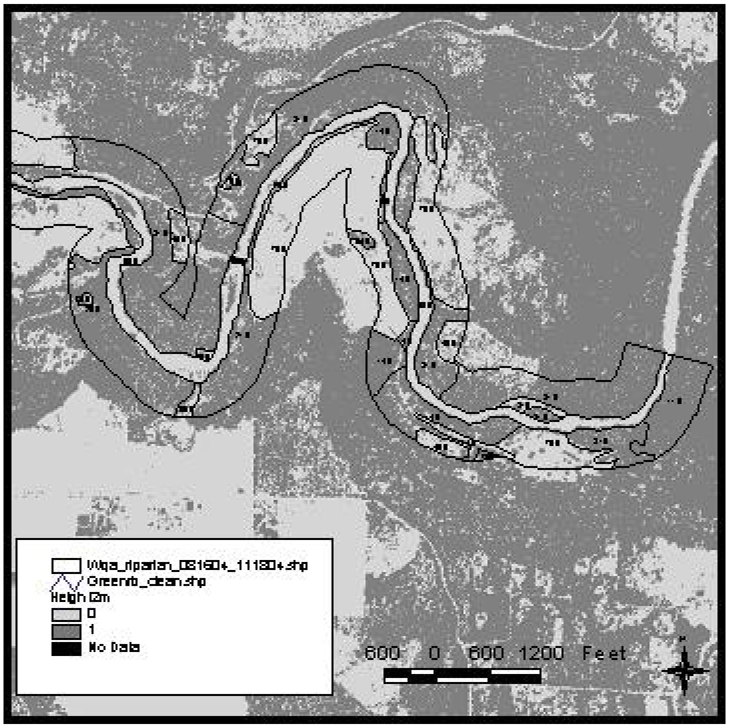
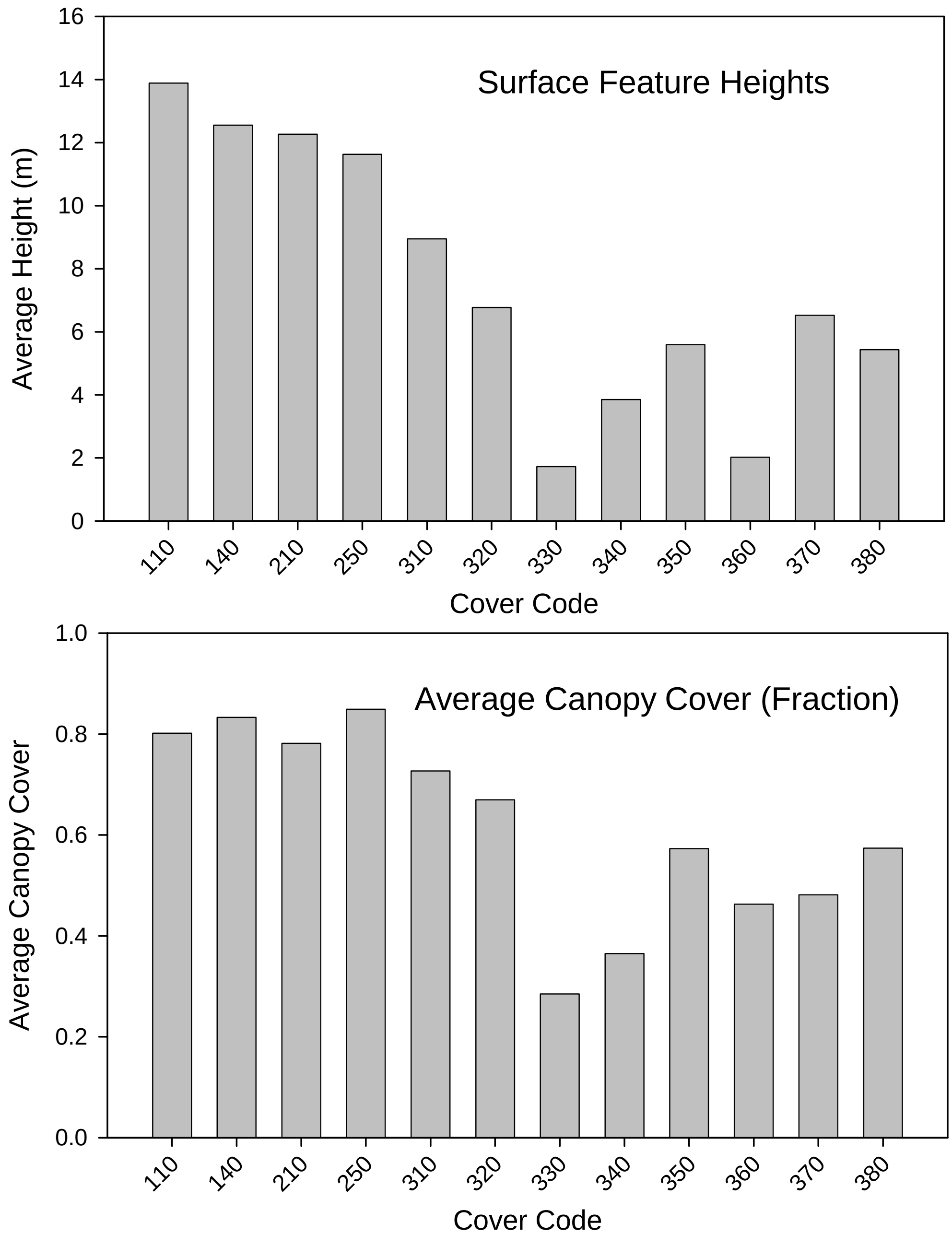


Figure 10. Example LiDAR 6x6 ft resolution Canopy Cover presence/absence (Height >2 m = 1, <=2 m = 0).

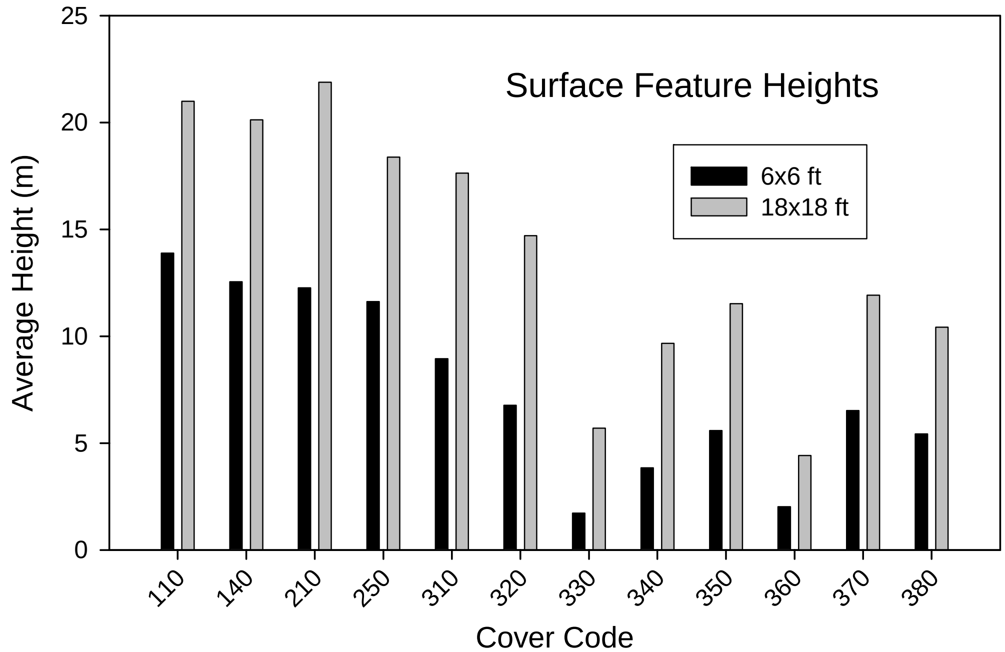
To further evaluate the orthophoto interpretation and the LiDAR derived vegetation characteristics, ArcView Spatial Analyst zonal statistics were calculated based on the classified polygon cover codes. The results for the 6x6 ft resolution DHM and Canopy Cover grids are summarized in Figure 11. The average heights and canopy cover shown in Figure 11 suggest that the delineation did capture the general patterns in tall, medium, and short tree cover. However, canopy cover derived from the LiDAR did not correspond well with the orthophoto classifications of dense, medium, and sparse cover. Average heights by cover classification based on the 18x18 ft resolution grid derived through nearest neighbor maximum analysis and resampling of the 6x6 ft DHM are compared to the results from the 6x6 ft DHM grid in Figure 12. This comparison indicates that estimated average tree height increased substantially as a result of the nearest neighbor maximum analysis, but the pattern among tall, medium, and short classifications remained the same.



110 = Conifer dominated Dense/Tall
140 = Conifer dominated Moderate/Tall
210 = Mixed Dense/Tall
250 = Mixed Moderate/Medium
310 = Deciduous Dense/Tall
320 = Deciduous Dense/Medium

330 = Deciduous Dense/Short
340 = Deciduous Moderate/Tall
350 = Deciduous Moderate/Medium
360 = Deciduous Moderate/Short
370 = Deciduous Sparse/Tall
380 = Deciduous Sparse/Tall

Figure 11. Zonal statistics by Cover Code based on 6x6 ft resolution DHM and LiDAR derived Canopy Cover.



110 = Conifer dominated Dense/Tall
140 = Conifer dominated Moderate/Tall
210 = Mixed Dense/Tall
250 = Mixed Moderate/Medium
310 = Deciduous Dense/Tall
320 = Deciduous Dense/Medium

330 = Deciduous Dense/Short
340 = Deciduous Moderate/Tall
350 = Deciduous Moderate/Medium
360 = Deciduous Moderate/Short
370 = Deciduous Sparse/Tall
380 = Deciduous Sparse/Tall

Figure 12. Comparison of zonal statistics by Cover Code based on 6x6 ft and 18x18 ft resolution DHM.

4.0. PRELIMINARY SHADE ANALYSIS

4.1 Current Method

Based on the field data, values for tree and building height and canopy density were assigned as first approximations. The assigned height and density values for the Current Method shade analysis are shown in Table 3.

Table 3. Cover code height and density assignments for application of Current Method

Code	Description	Height (m)	Density (%)	OH (m)
110	Conifer dominated Dense/Tall	35.0	90%	0.0
140	Conifer dominated Moderate/Tall	35.0	80%	0.0
210	Mix of Conifer and Hardwood Dense/Tall	35.0	90%	0.0
250	Mix of Conifer and Hardwood Moderate/Medium	25.0	80%	0.0
310	Hardwood dominated Dense/Tall	35.0	90%	0.0
320	Hardwood dominated Dense/Medium	25.0	90%	0.0
330	Hardwood dominated Dense/Short	15.0	90%	0.0
340	Hardwood dominated Moderate/Tall	35.0	80%	0.0
350	Hardwood dominated Moderate/Medium	25.0	80%	0.0
360	Hardwood dominated Moderate/Short	15.0	80%	0.0
370	Hardwood dominated Sparse/Tall	35.0	50%	0.0
380	Hardwood dominated Sparse/Medium	25.0	50%	0.0
420	Shrub Dense/Medium	3.0	90%	0.0
430	Shrub Dense/Short	1.5	90%	0.0
450	Shrub Moderate/Medium	3.0	80%	0.0
460	Shrub Moderate/Short	1.5	80%	0.0
480	Shrub Sparse/Medium	3.0	15%	0.0
490	Shrub Sparse/Short	1.5	15%	0.0
500	Buildings	10.0	100%	0.0
510	Buildings-Apartments	10.0	50%	0.0
520	Buildings-Residential	5.0	50%	0.0

The resulting Effective Shade prediction for August 3, 1998 at 100 ft intervals along the mainstem Green River is shown in Figure 13. Results smoothed over approximate 250 m intervals (centered means) consistent with the CE-QUAL-W2 model delineation are also shown in Figure 13. Effective Shade estimates based on hemispherical photo analysis are shown for comparison. One observation that can be made from a review of Figure 13 is that hemispherical photos taken on either stream bank appear to over-estimate Effective Shade over the river surface. This is due to inclusion of overhanging bank vegetation and over-representation of stream side tree cover in these photos. Lack of mid-channel photographs compromises the ability to validate any shade modeling approach.

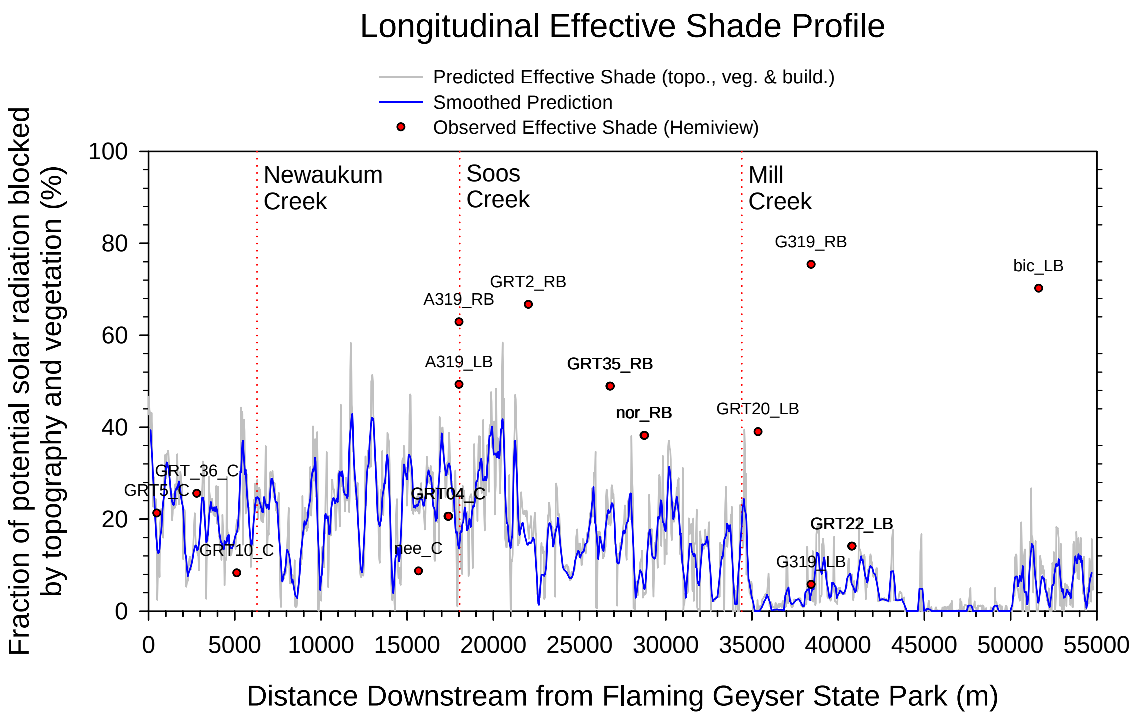


Figure 13. Comparison of model-predicted Green River Effective Shade profile using Current Method with Effective Shade estimated from hemispherical photo analysis.

4.2 LiDAR Method 1

Model-predicted Green River Effective Shade and comparisons to hemispherical photo estimates of Effective Shade based on LiDAR Method 1 are shown in Figure 14. Predicted Effective Shade is generally lower and more variable using Method 1 than using the Current Method primarily due to lower and more spatially variable estimated tree heights used in Method 1.

4.3 LiDAR Method 2

Model-predicted Green River Effective Shade and comparisons to hemispherical photo estimates of Effective Shade based on LiDAR Method 2 are shown in Figure 15. Method 2 predicted Effective Shade is only slightly higher and slightly less variable than predicted using Method 1. This seems reasonable since the estimated tree heights increased slightly and grid resolution was coarsened as a result of the nearest neighbor maximum analysis and grid resampling. Result from Method 2 appear qualitatively to be most similar to the field estimates of Effective Shade made at the center of the river channel. Unfortunately, only a few locations in the upper river were wadable enough to allow mid-channel photos to be taken without the need of a boat.

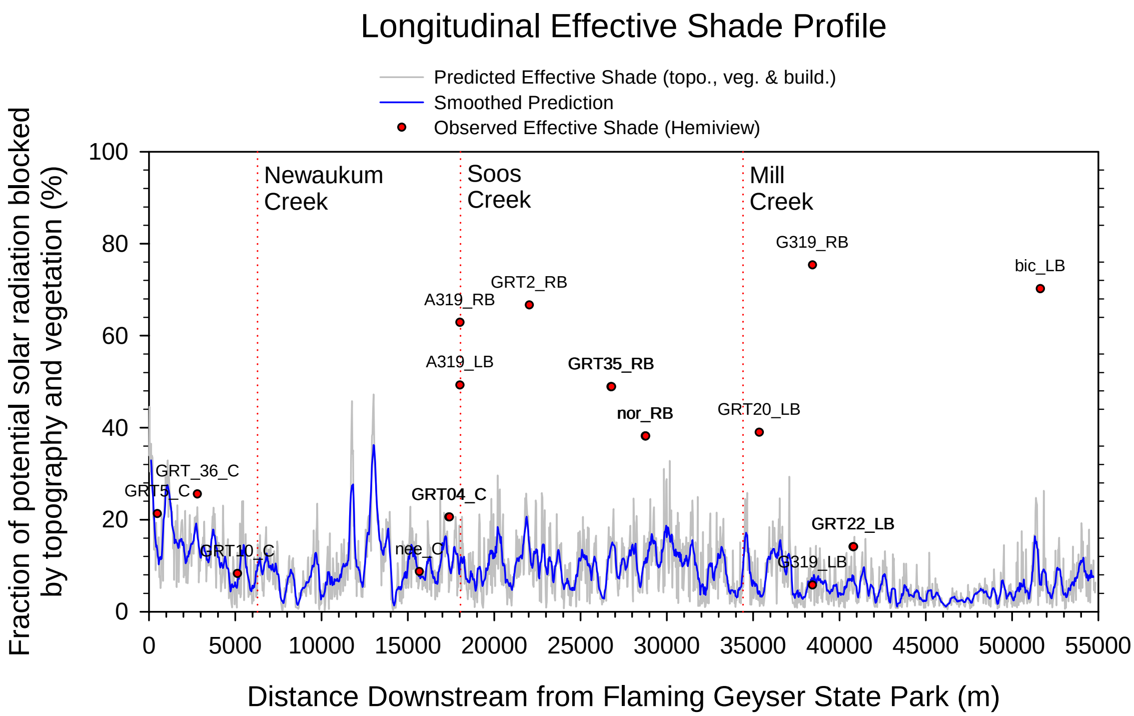


Figure 14. Comparison of model-predicted Green River Effective Shade profile using LiDAR Method 1 with Effective Shade from hemispherical photo analysis.

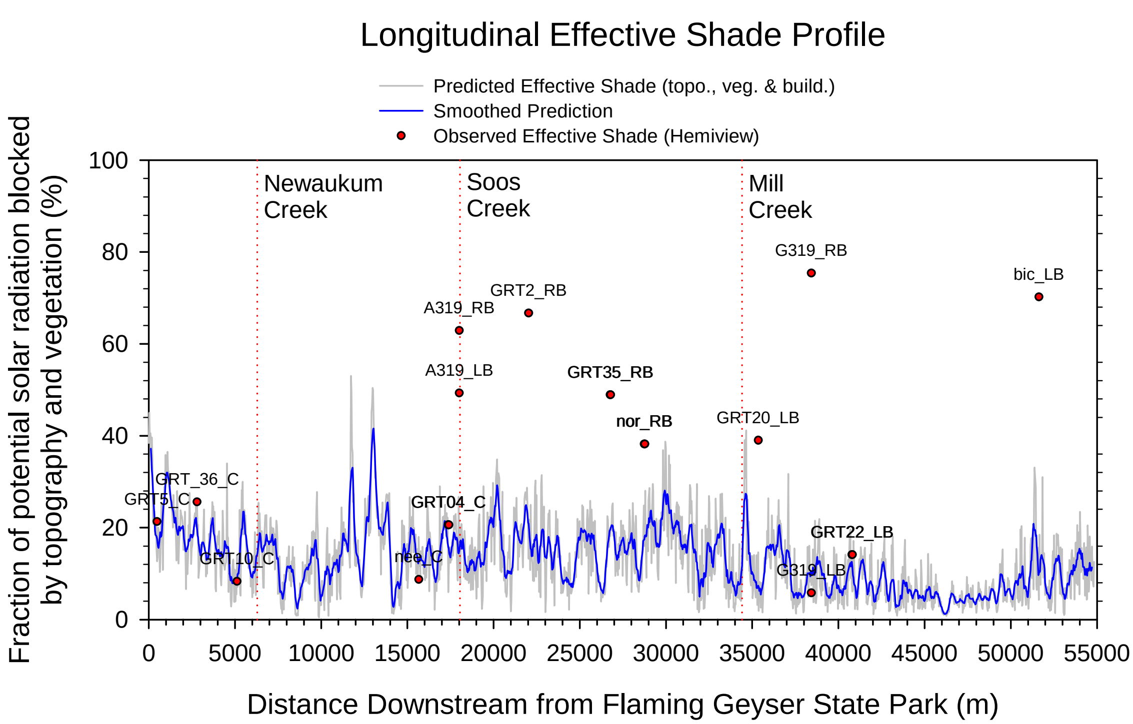


Figure 15. Comparison of model-predicted Green River Effective Shade profile using LiDAR Method 2 with Effective Shade from hemispherical photo analysis.

4.4 Sammamish River Data and Analysis

Parallel to the Green River Riparian Study, a similar effort was undertaken in August and September 2004 along the Sammamish River mainstem to provide similar data for development of the shade component of the Sammamish River CE-QUAL-W2 model. Because the Sammamish River is smaller and more safely navigated by small boat along the entire reach, it was possible to take more hemispherical photos from the river center. Two separate photo surveys were conducted. The first using a double sea-kayak that covered the upstream portion of the river to Woodinville (August 30, 2004) and a second survey using a Zodiac that covered the portion of the river from Woodinville to the mouth (October 10, 2004).

The necessary DSM and DGM grids and hemispherical photos were processed in the same way as described above for the Green River analysis and Ecology's shade model was used to predict Effective Shade based on the LiDAR Method 1 and 2 inputs (assuming a canopy density of 90 percent and zero vegetation overhang distance).

4.4.1 LiDAR Method 1

Model-predicted Sammamish River Effective Shade and comparisons to hemispherical photo estimates of Effective Shade based on LiDAR Method 1 are shown in Figure 16. With a few exceptions, there appears to be a strong correspondence between model-predicted and field-based estimates of Effective Shade using Method 1.

4.4.2 LiDAR Method 2

Model-predicted Sammamish River Effective Shade and comparisons to hemispherical photo estimates of Effective Shade based on LiDAR Method 2 are shown in Figure 17. Qualitatively, there appears to be an even stronger correspondence between model-predicted and field-based estimates of Effective Shade using Method 2.

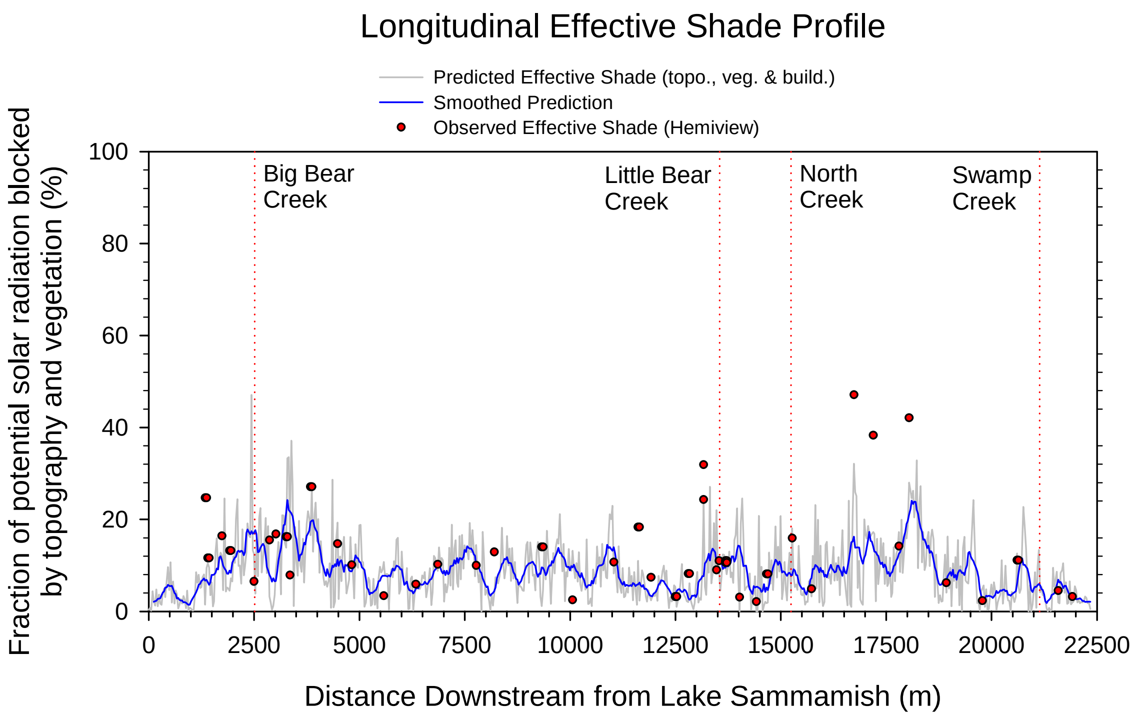


Figure 16. Comparison of model-predicted Sammamish River Effective Shade profile using LiDAR Method 1 with Effective Shade from hemispherical photo analysis.

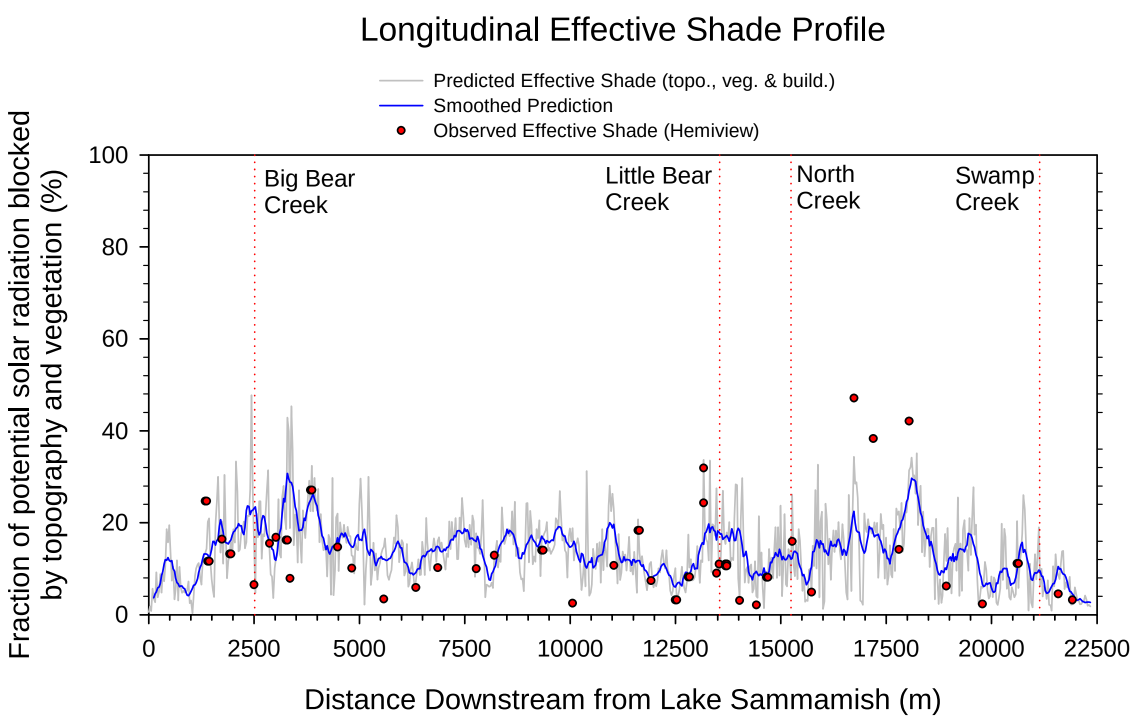


Figure 17. Comparison of model-predicted Sammamish River Effective Shade profile using LiDAR Method 2 with Effective Shade from hemispherical photo analysis.

5.0. SHADE MODEL SENSITIVITY ANALYSIS

A number of analyses were performed to assess the sensitivity of the shade model to the shade model inputs – primarily canopy density, tree height, and vegetation overhang. An initial assessment was also made of the relative importance of shade from buildings (primarily warehouses, apartment buildings and residential homes) along the Green River. The results of these shade model sensitivity analyses are presented below.

5.1 Buildings

Although it may be possible to develop a digital elevation model of structures by intersecting an available GIS coverage of impervious surfaces with the DHMs, an initial assessment of the relative importance of buildings was assessed using the Current Method for the Green River, which included delineations of large warehouses, apartment/condominium complexes and residential housing areas. Figure 18 displays the relative contribution of buildings to Effective Shade along the Green River mainstem. It appears that the contribution of shade from buildings and homes along the river is negligible, with the possible exception of shade from residential housing along the reach through the City of Auburn. It is quite possible that the Effective Shade from this residential area is overestimated due to the fact that the classified residential area includes streets, lawns and vegetation surrounding the homes. More explicit delineation of structures using the available LiDAR and impervious surface coverages will provide a more accurate assessment of the Effective Shade contribution of buildings along these rivers.

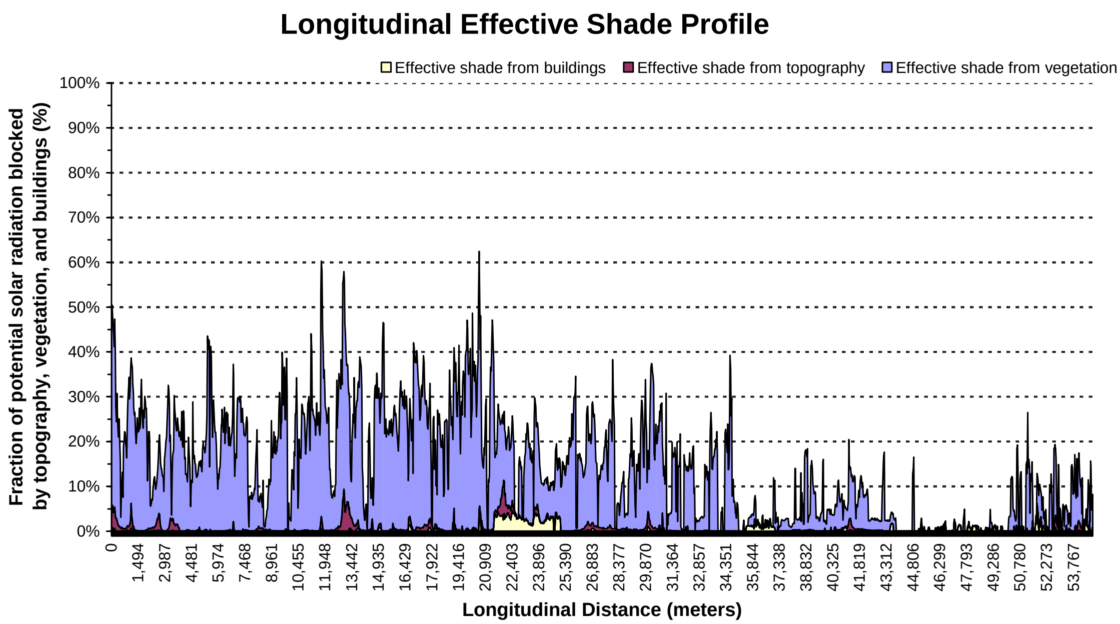


Figure 18. Assessment of shade from buildings. Green River Current Method.

5.2 Canopy Density

The sensitivity of the shade model to canopy density was assessed for the Green and Sammamish Rivers using Method 2 approach and 80, 90 (base case), and 100 percent canopy density as inputs to the model. Model results for the Green and Sammamish Rivers smoothed over approximate 250 m intervals (centered means) are shown in Figures 19 and 20, respectively. Interestingly, neither model (Green or Sammamish) appear to be very sensitive to changing canopy density from 90 to 80 %. However, where vegetation coverage is most extensive (i.e., above Mill Creek in the Green and below North Creek on the Sammamish), the model is fairly sensitive to changing canopy density from 90 to 100 percent. In the Sammamish model, higher canopy density may account for the lack of fit between the initial model (with constant 90 percent canopy density) and observations based on the hemispherical photo analysis.

5.3 Tree Height

The sensitivity of the shade model to tree height was assessed for the Green and Sammamish Rivers using Method 2 approach and using 0.5x and 1.5x the LiDAR Method2 DHM-derived tree heights as inputs to the model. Model results for the Green and Sammamish Rivers smoothed over approximate 250 m intervals (centered means) are shown in Figures 21 and 22, respectively. Neither the Green or Sammamish River shade models appear to be very sensitive to changing input tree heights ±50 percent.

5.4 Vegetation Overhang

Since the effect of vegetation overhang is not currently included in the CE-QUAL-W2 water quality model, the sensitivity of the Green and Sammamish River shade models to overhanging vegetation was assessed using the Method 2 approach and 0 (base), 1, and 2 m vegetation overhang distances (see Figures 23 and 24). Vegetation overhang distances observed during the Green River field study were never greater than 2 m. Qualitatively, vegetation overhang is rare along most of the Sammamish River, with the exception of the reaches below Little Bear Creek where riparian vegetation occurs down to the rivers edge in some areas. In general, the Green River shade model was relatively insensitive to overhanging vegetation distances of 1 or 2 m and was less sensitive to overhanging vegetation than the Sammamish River model. Less sensitivity to overhanging vegetation is consistent with the generally wider channel along the Green River.

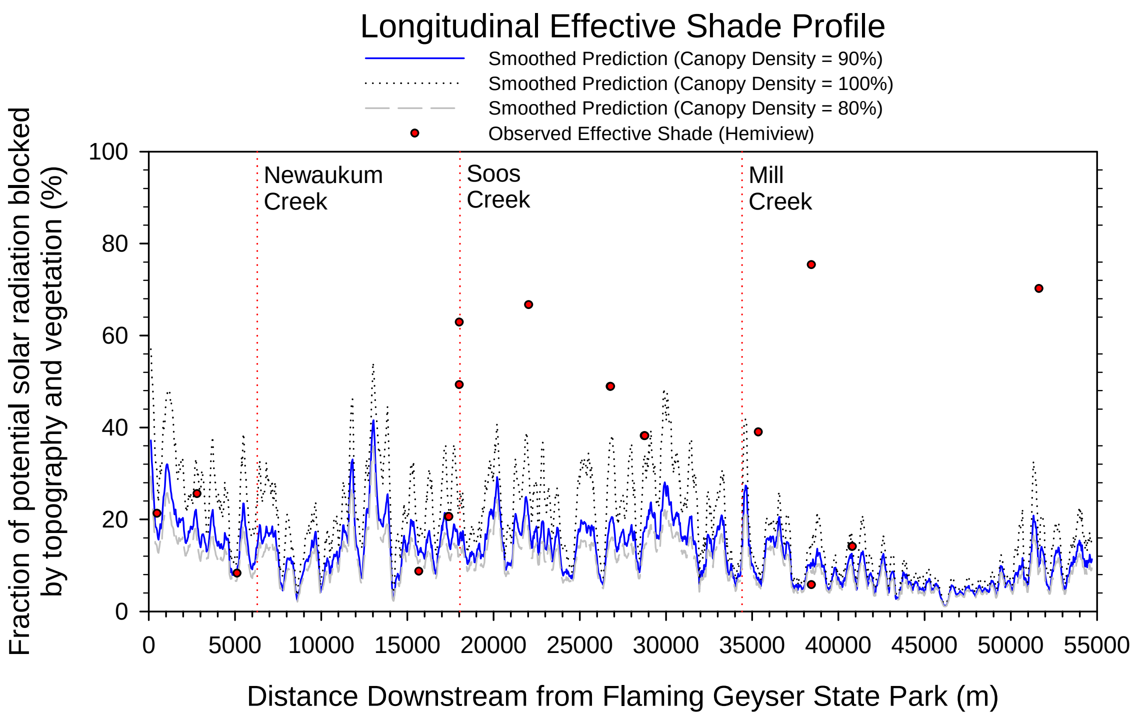


Figure 19. Sensitivity of shade model to changes in canopy density. Green River LiDAR Method 2 with Effective Shade from hemispherical photo analysis.

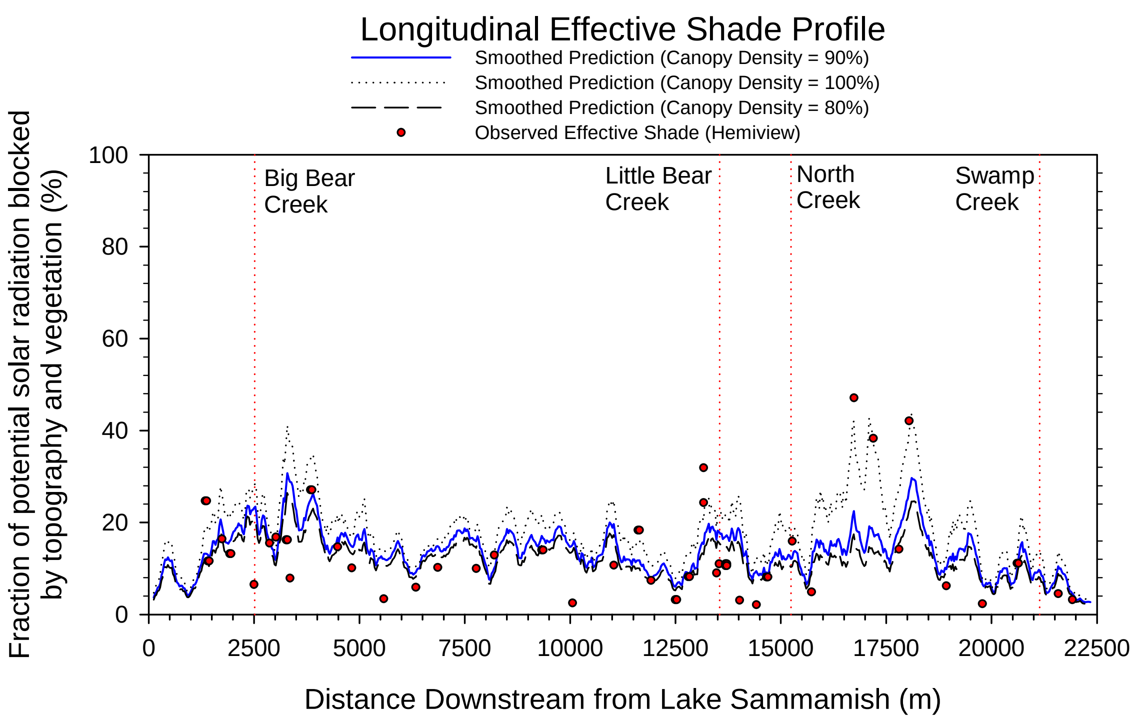


Figure 20. Sensitivity of shade model to changes in canopy density. Sammamish River LiDAR Method 2 with Effective Shade from hemispherical photo analysis.

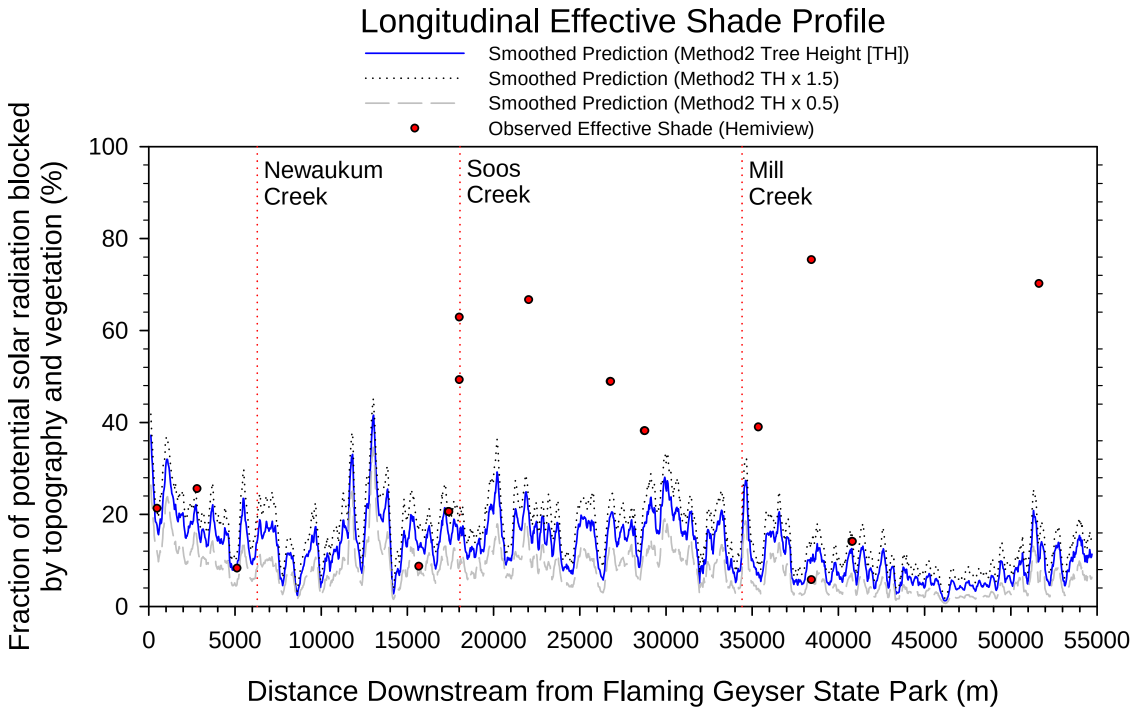


Figure 21. Sensitivity of shade model to changes in tree height. Green River LiDAR Method 2 with Effective Shade from hemispherical photo analysis.

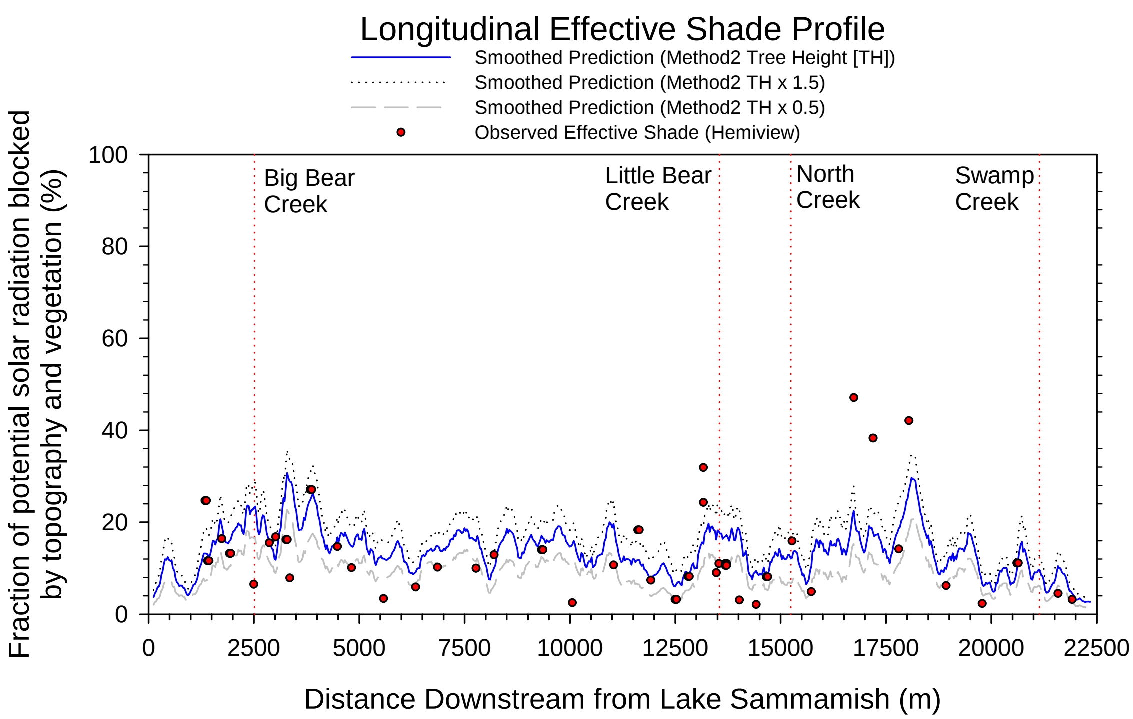


Figure 22. Sensitivity of shade model to changes in tree height. Sammamish River LiDAR Method 2 with Effective Shade from hemispherical photo analysis.

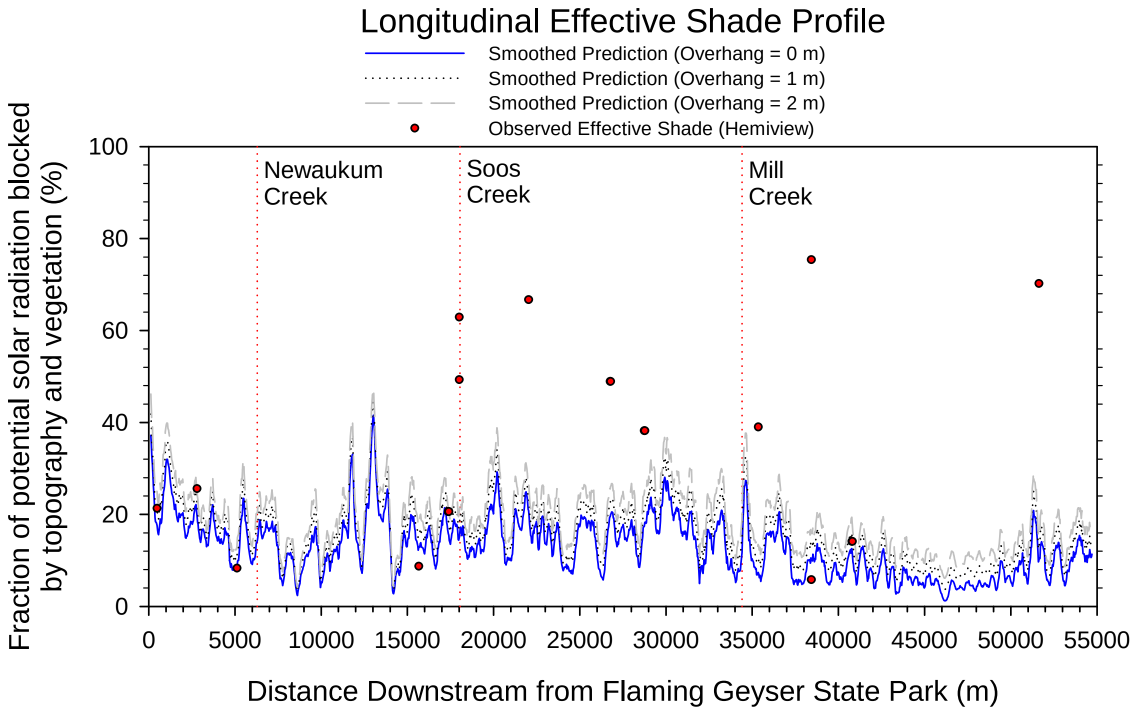


Figure 23. Sensitivity of shade model to changes in vegetation overhang. Green River LiDAR Method 2 with Effective Shade from hemispherical photo analysis.

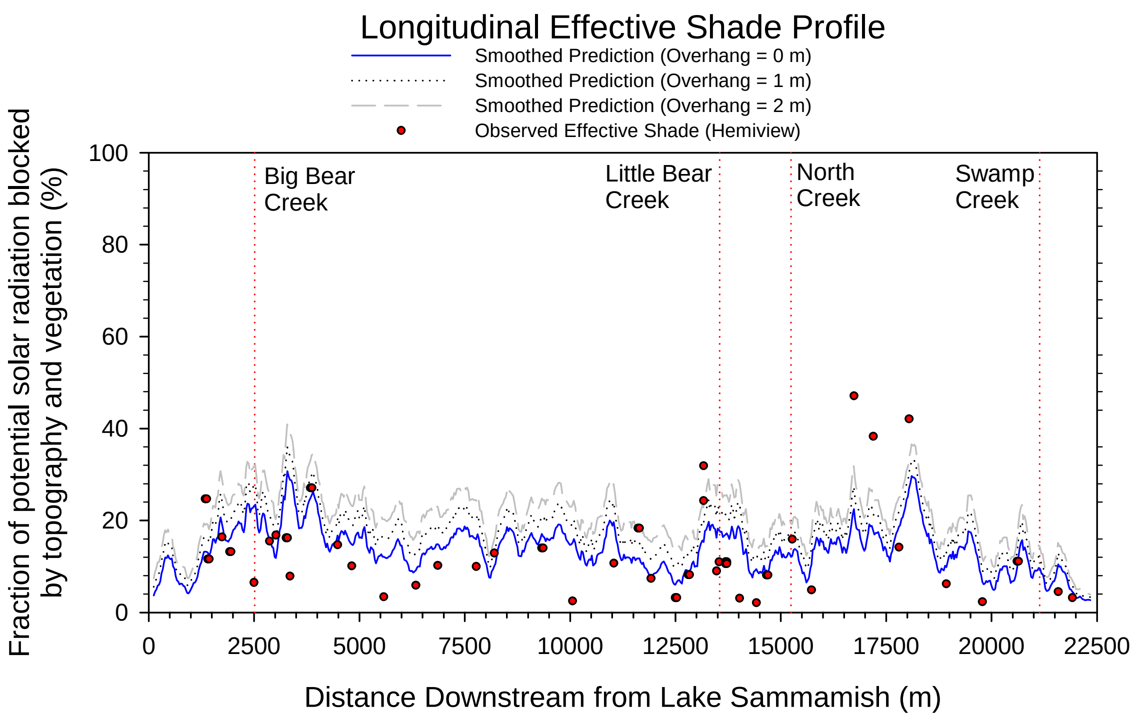


Figure 24. Sensitivity of shade model to changes in vegetation overhang. Sammamish River LiDAR Method 2 with Effective Shade from hemispherical photo analysis.

6.0. DISCUSSION

Scatter plots of model-predicted and observed Effective Shade for the Green River (LiDAR Method 2) are shown in Figure 25. Clearly, observed Effective Shade based on photographs taken from the right or left banks over-estimates Effective Shade over the river channel. Removal of left and right bank observed Effective Shade indicates that observations and predictions are fairly consistent, but too few data points are available to determine if there is a statistically significant relationship between observed and predicted Effective Shade (Figure 26). Addition of Sammamish River observations and predictions (Figure 27) confirms the correlation between observed and predicted Effective Shade, and when the regression is forced through zero indicates a 1:1 relationship. However, this relationship should be more firmly established by:

- Refinements in the approach to development of the DHM
- Method to calculate predictions at the same locations as observation points (currently, model predictions are only possible at set river intervals)
- More spatially explicit canopy density estimates
- Spatially explicit consideration of shading by buildings, apartment complexes and residential housing along the river (although initial sensitivity analyses indicate that structures contribute minimally to Effective Shade along the Green River mainstem)
- Refinement in the methods used to take and process hemispherical photos
- Additional data collection in smaller tributary basins that would provide comparisons at higher levels of Effective Shade.

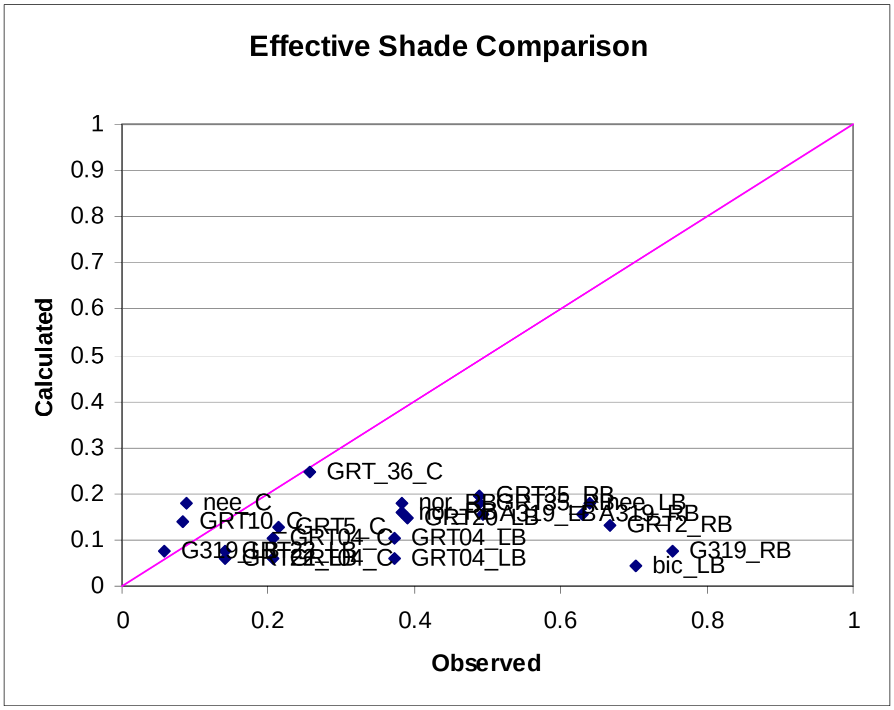


Figure 25. Comparison of observed and model-predicted Green River Effective Shade using Method 2 (center, left and right bank hemispherical photo estimates).

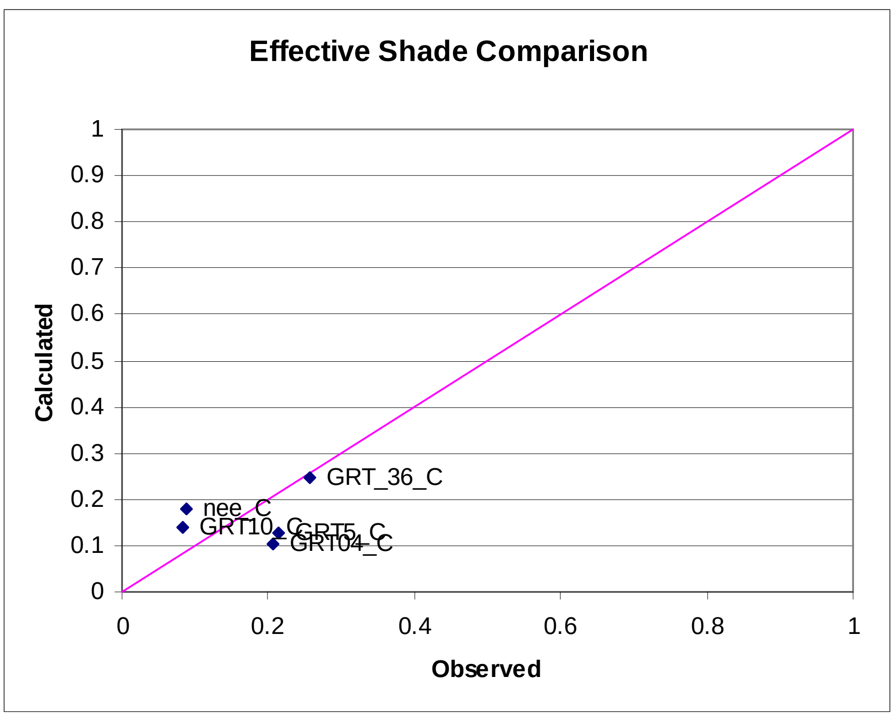


Figure 26. Comparison of observed and model-predicted Green River Effective Shade using Method 2 (river center hemispherical photo estimates only).

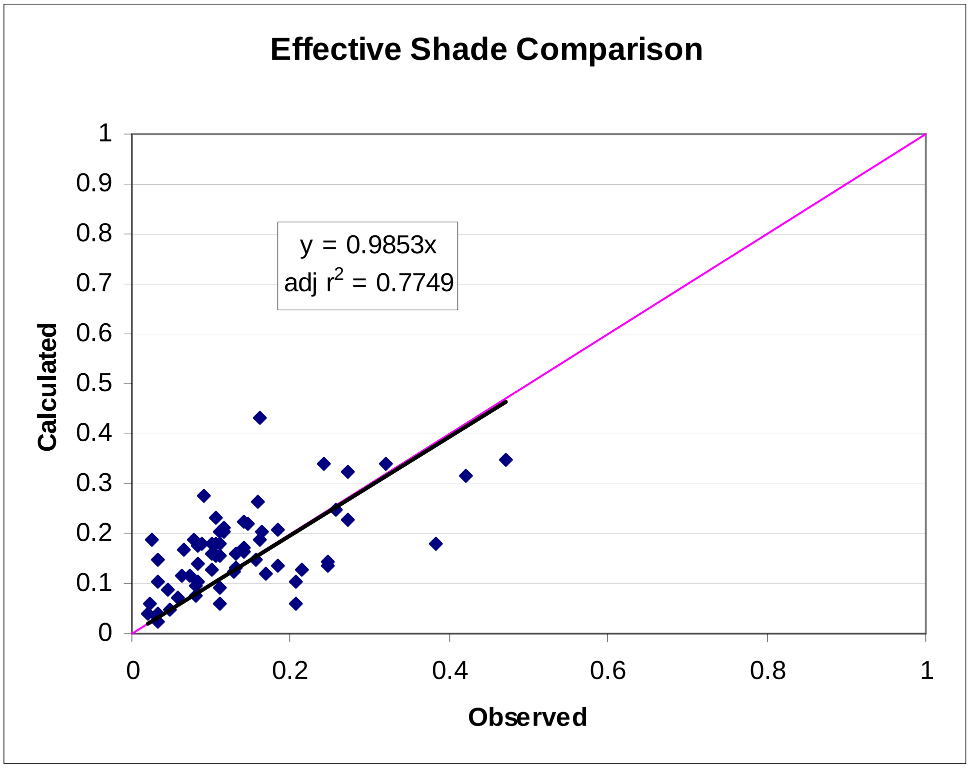


Figure 27. Comparison of observed and model-predicted Green and Sammamish River Effective Shade using Method 2 (river center hemispherical photo estimates only).

7.0. CONCLUSIONS AND RECOMMENDATIONS

The current method used for development of riparian and topographic shade inputs for river and stream temperature modeling (i.e., orthophoto classification and field surveying) appears to be heavily dependent on the experience of the photo analyst and field crew and their ability to capture the spatial variability and accurately average this variability over the delineated cover types. Based on the preliminary evaluation of the use of high-resolution LiDAR to remotely characterize vegetation cover (primarily tree height), a more spatially explicit and accurate assessment of tree cover appears to be possible. Canopy Density, is also highly variable and depends strongly on whether the observer is located under dense tree cover or in more patchy environments. However, it seems intuitive that individual trees remove a similar (and significant) amount of solar radiation when they are present. Although Canopy Density beneath coniferous tree cover may typically be higher than under deciduous tree cover, from the vantage point of the stream looking through the trees, one might conclude that these differences are minor and that control of the amount of solar radiation that reaches the stream surface is more a function of the density/extent of tree cover than the type of tree. Regardless, it seems reasonable that if one can accurately assign tree heights at an 18x18 ft resolution, a uniform canopy density of 90 percent would appear to be a reasonable first approximation for the river shade model. Using the LiDAR-derived tree heights and a uniform Canopy Density of 90 percent results in an encouraging correlation between model-predicted and observed Effective Shade when the observations are made in the center of the river channel.

It is recommended that additional hemispherical photos be collected along the Green River mainstem and in smaller tributary basins in August 2005 to provide more observations over a broader range of Effective Shade values for use in developing the best approach to incorporating the available LiDAR data into the shade modeling framework.

Further investigation and analysis is needed to develop a method to estimate spatially explicit canopy density estimates from the available LiDAR data.

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